Improving Prediction of Extreme Weather Events using Multi-Model Ensembles

A Presentation to the
NOAA Science Advisory Board

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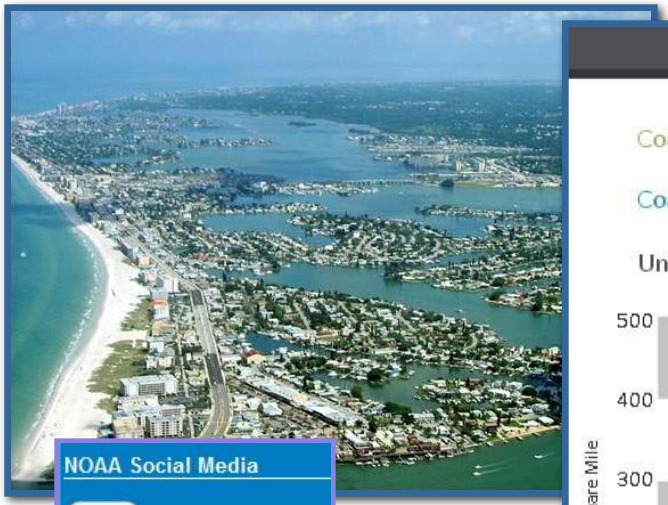
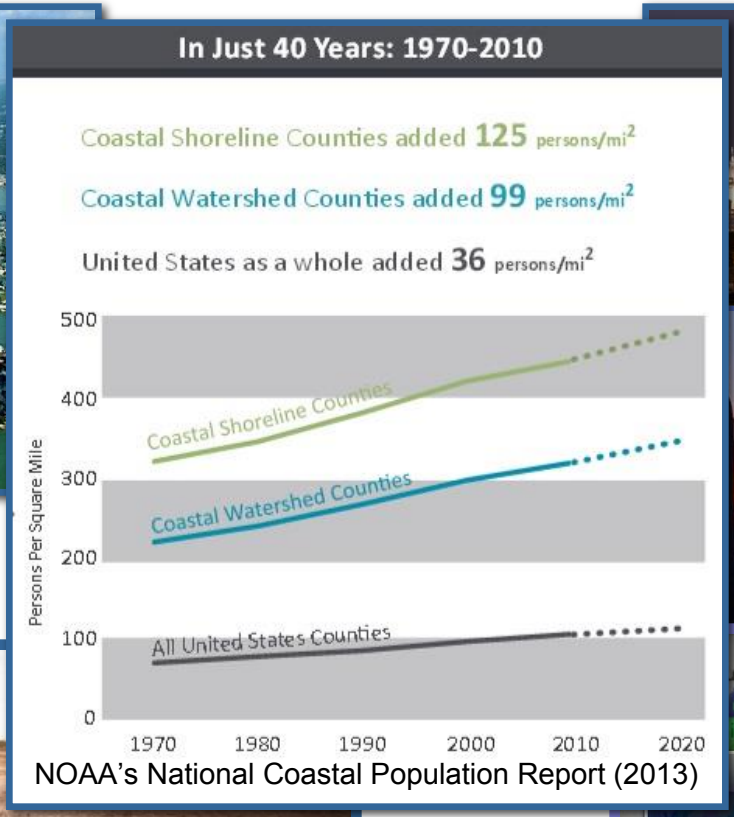
4-15-2014

Outline

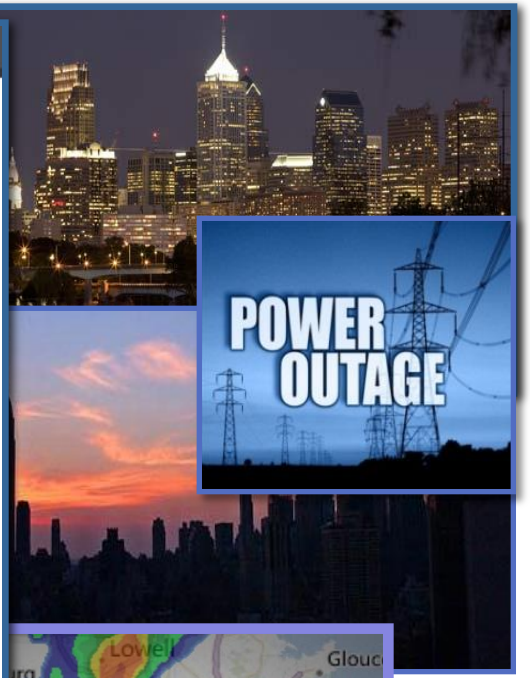
- Motivation
- Basis for Multi-model Ensembles
- Examples of Use
  - Forecaster perspective
  - User perspective
- Future Directions

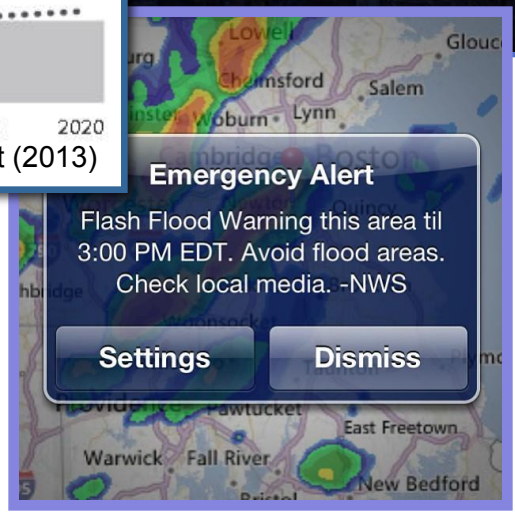
Changing World



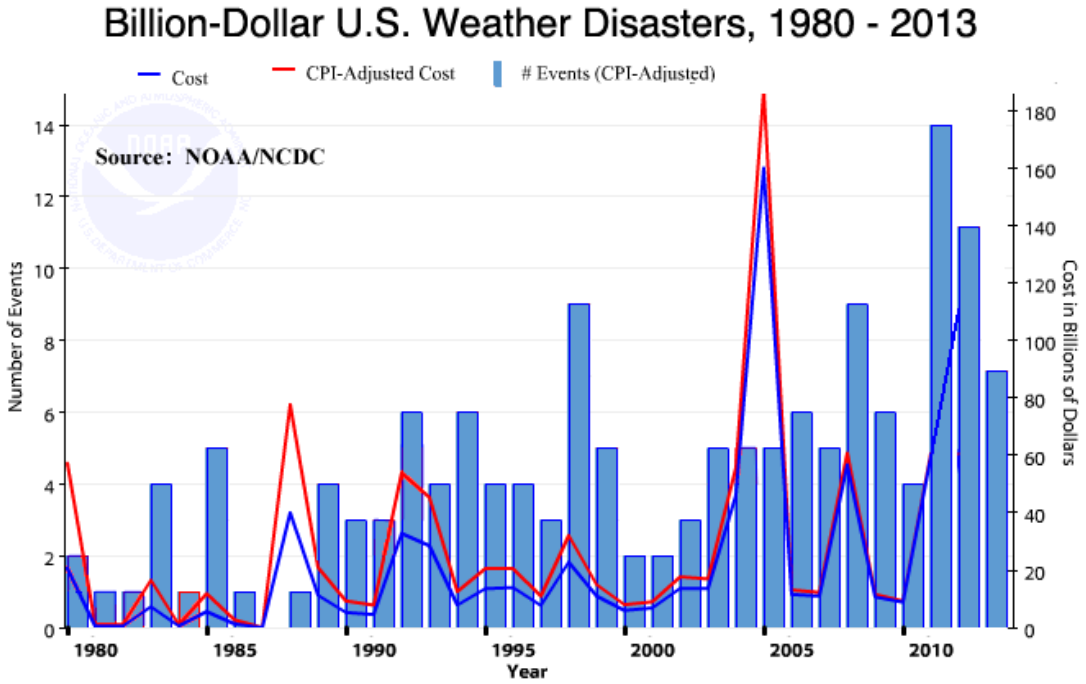


NOAA's National Coastal Population Report (2013)



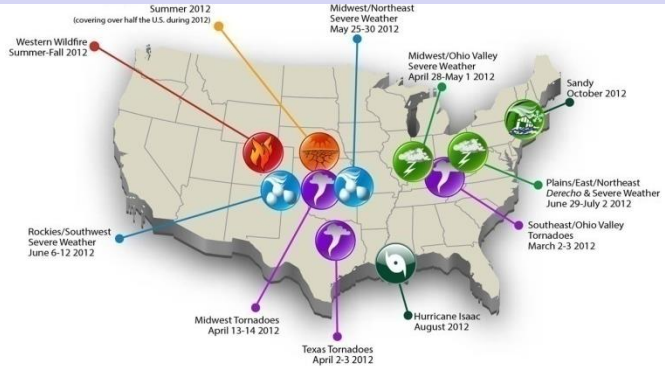


Changing Extremes



2011

2012



2013

Changing Users

Ike 2008

Surge 18 hours prior to landfall

Atlanta 2014

City gridlock despite 8 hour warning lead time

Decisions made at longer lead times demand more accurate and consistent predictions

2010 Blizzard

City gridlock despite 18 hour blizzard warning lead time

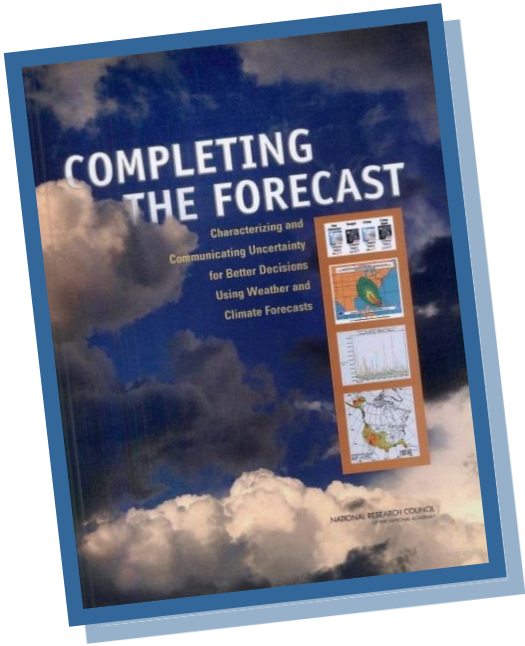
NYC Report:
"The weather forecast for the storm got significantly worse rather quickly…Due to the late change in the forecast… agencies …were not mobilized expeditiously.

Users Demand an early and consistent message

Changing Forecast

2006 National Research Council Report

"… compelling reasons for Enterprise to transition to a new paradigm … in which uncertainty is an integral and essential component of all forecasts."



2008 American Meteorological Society Statement

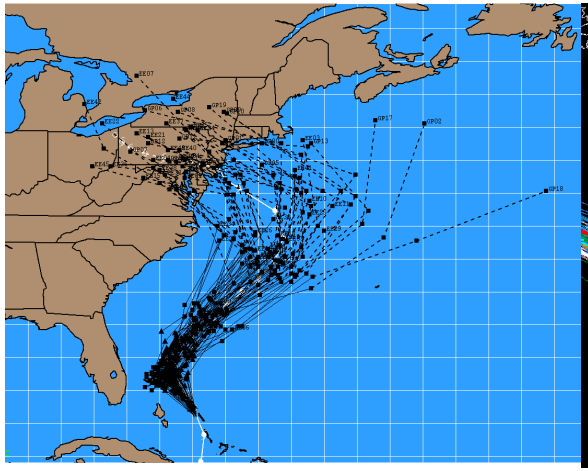
"Ideally, all weather forecasts would include information that accurately quantifies their uncertainty."

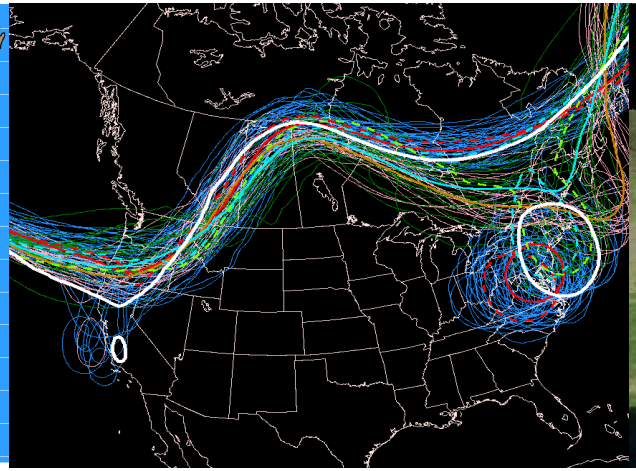
Ensembles Meet the Challenge

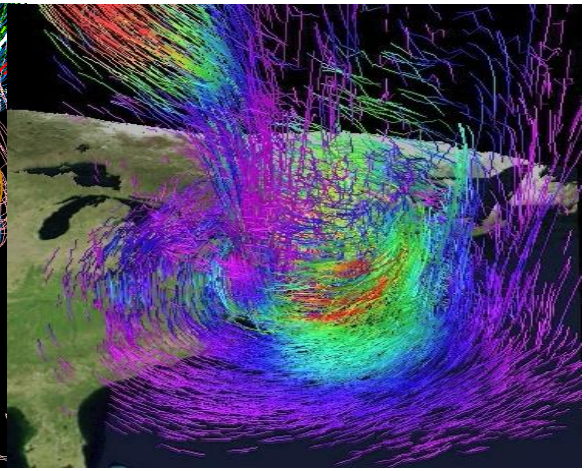
Improved Accuracy

Improved Consistency

Improved Basis for Communication of Uncertainty and Societial Impacts



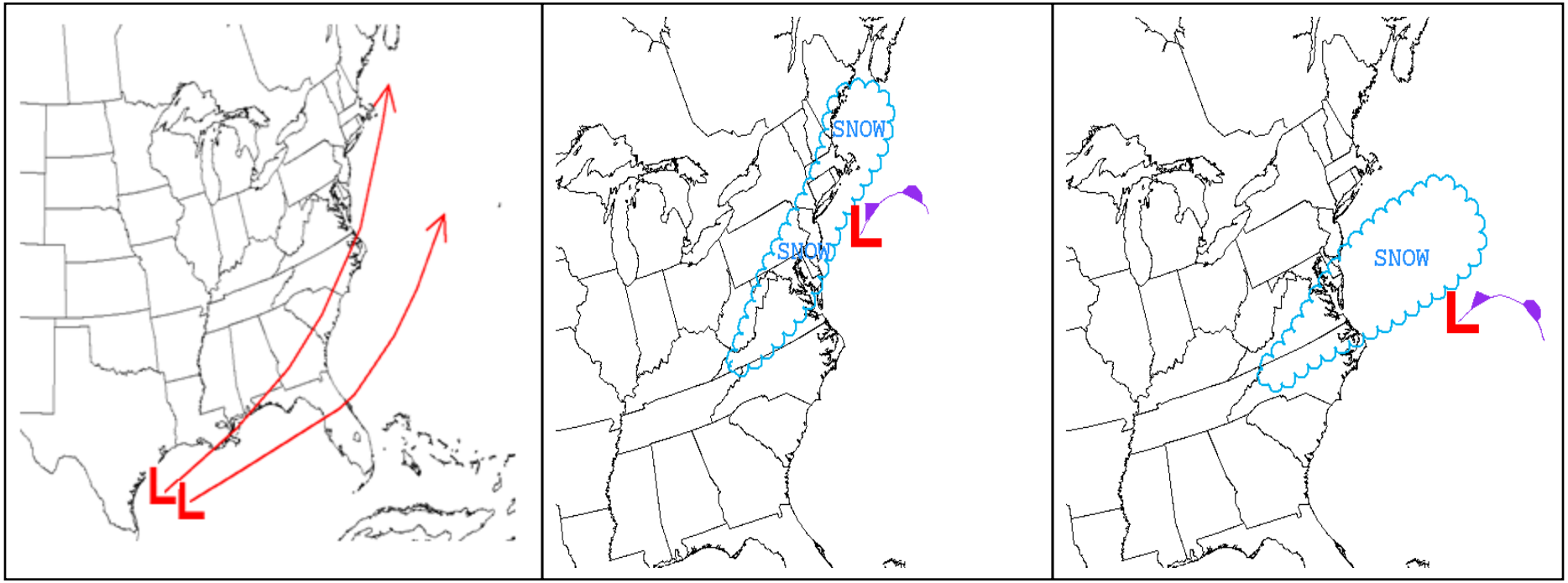




Basis for Ensembles

Slightly different:
-Initial Conditions

Initialization | Forecast Possibility #1 | Forecast Possibility #2



Today | Three Days Later

Basis for Ensembles

Slightly different:
-Physics representations

Real World

Model Representation

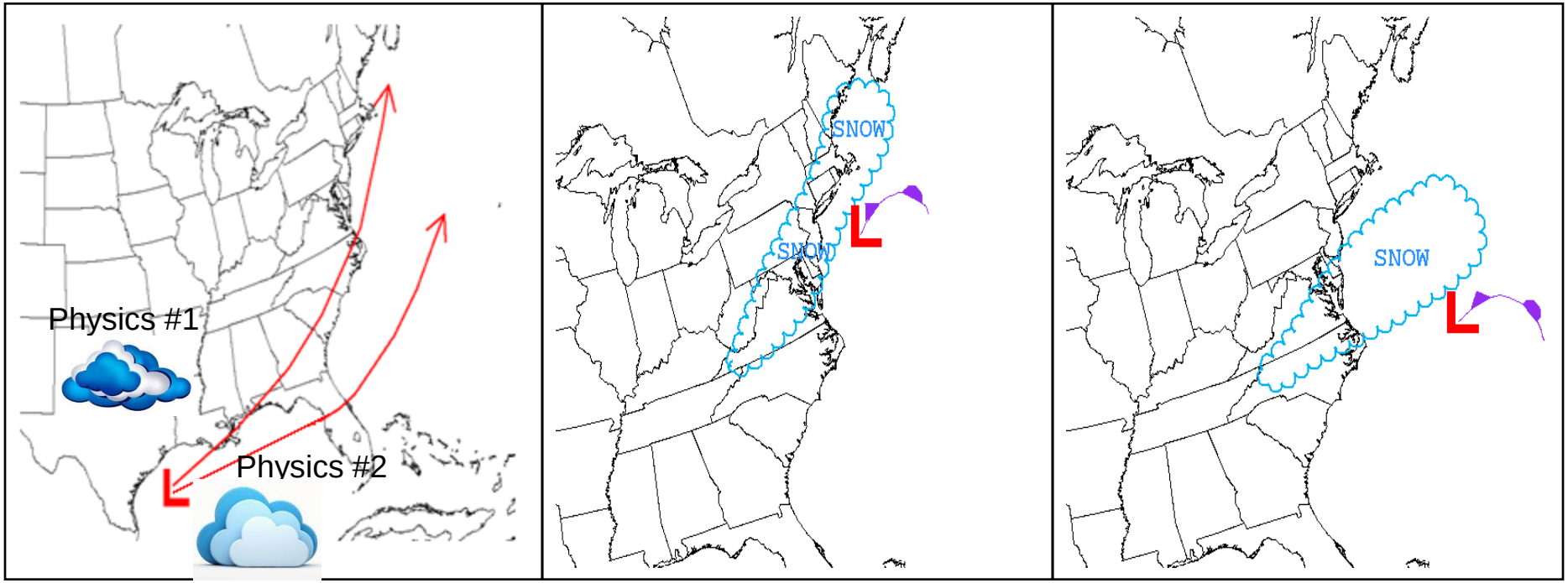
Physics Package #1

Physics Package #2

Basis for Ensembles

Slightly different:
-Physics representations

Initialization | Forecast Possibility #1 | Forecast Possibility #2

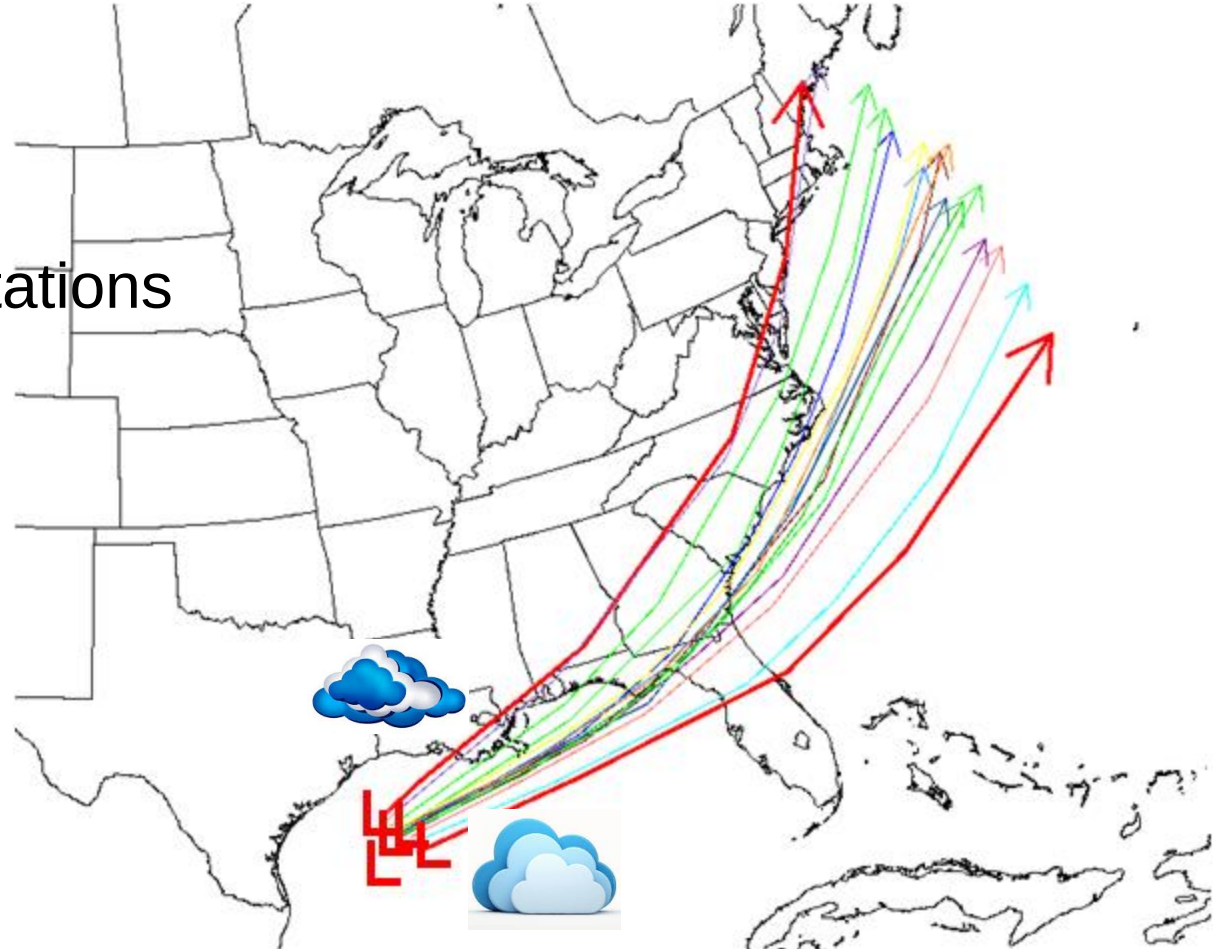


Today | Three Days Later

Basis for Ensembles

Ensembles provide an envelope of possible solutions

Slightly different:
-Initial conditions
-Physics representations



Storm Tracks Predicted Over a 3 Day Period

Basis for Multi-Model Ensembles

Theoretical: Differences in initial conditions and physics are sufficient.

Practical: Difficult to represent all errors arising from a model system.

What if we combined model systems, such that we have a sampling of different analyses, perturbation methods, and forecast models?

Model systems have unique bias characteristics that

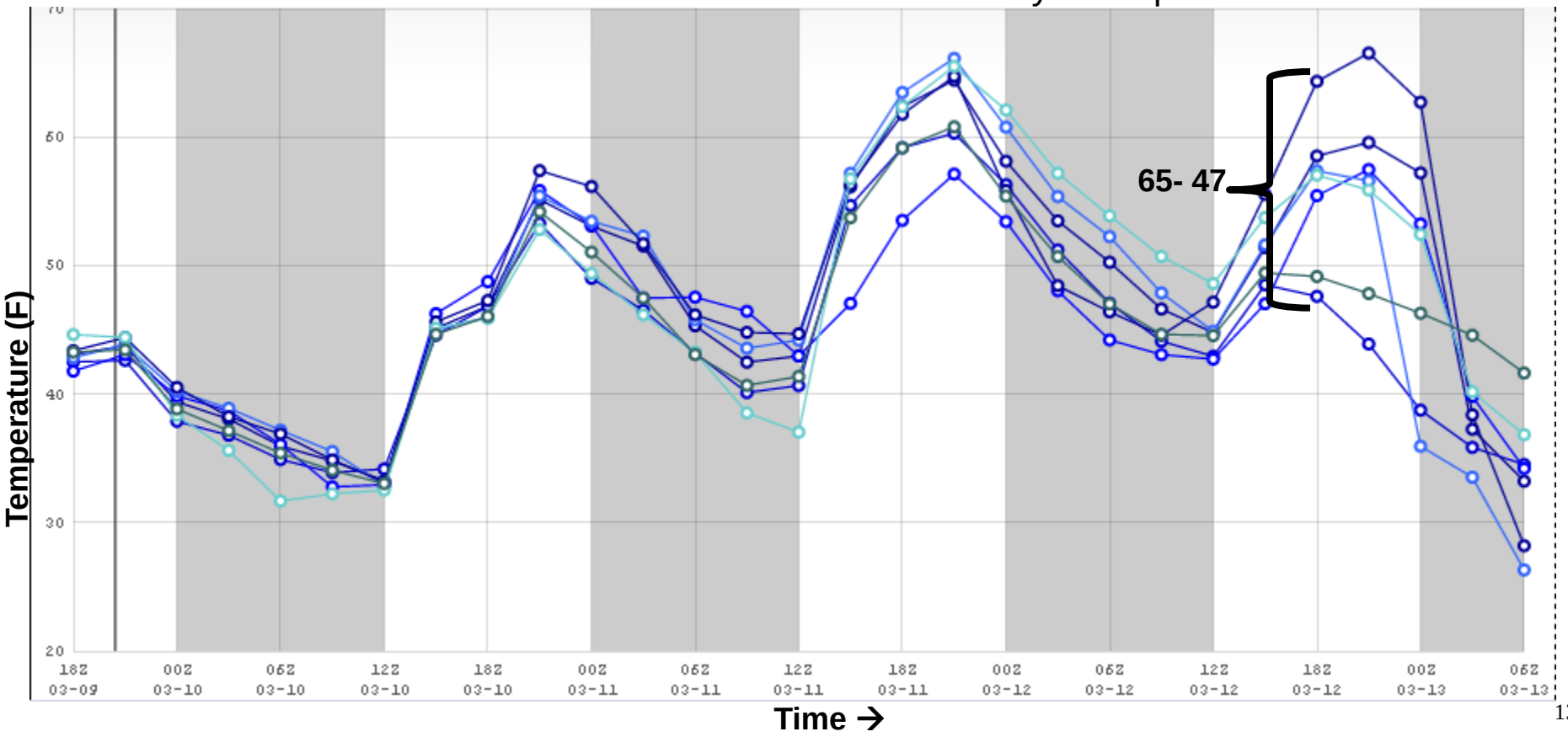
- -May complement each other
  - (Model A too warm, model B too cold)
- -May more fully sample the true uncertainty
  - (Model A+B gives a larger, more correct spread)

Temperature Prediction

Temperature Forecast for DC on March 12th

MODEL A

Slightly different:
-Initial conditions
-Physics representations

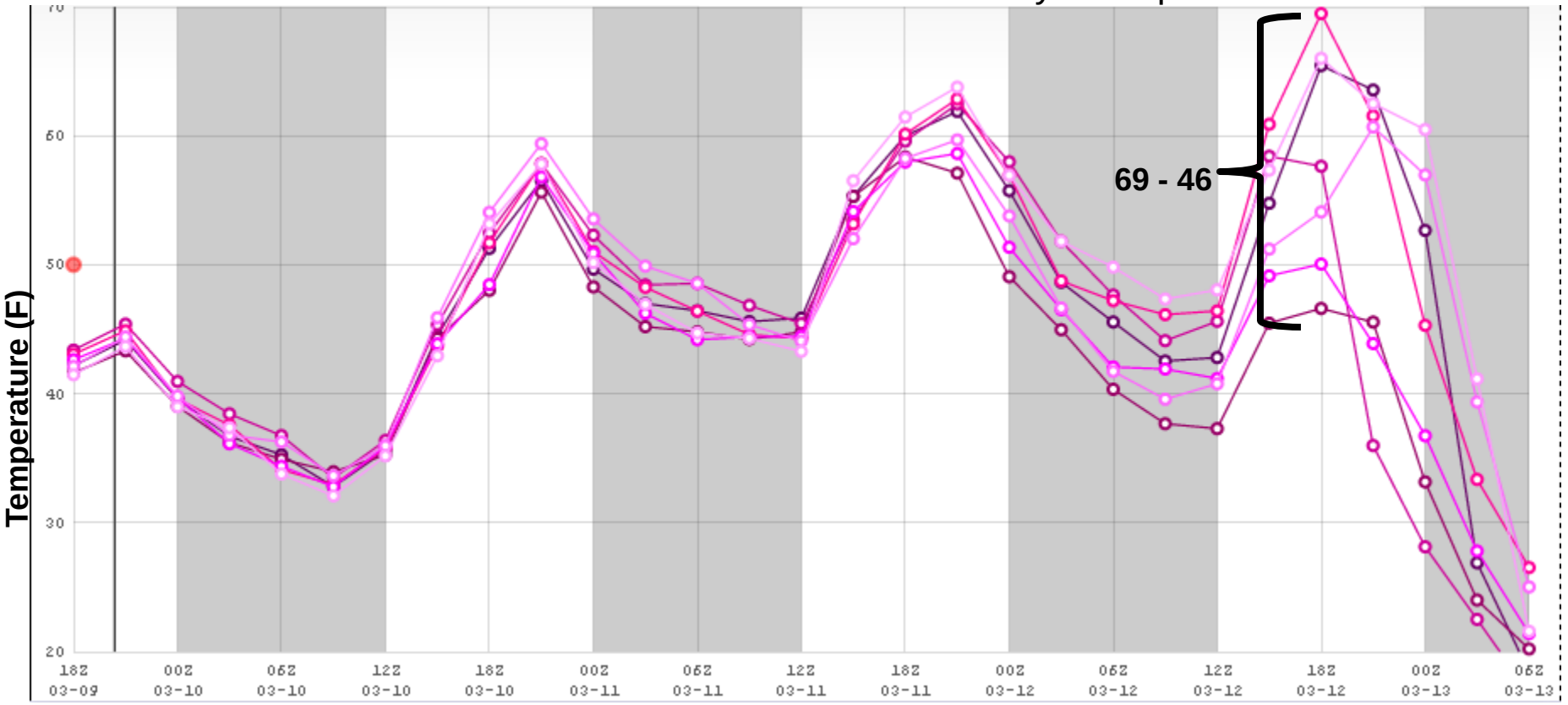


Temperature Prediction

Temperature Forecast for DC on March 12th

MODEL B

Slightly different:
-Initial conditions
-Physics representations

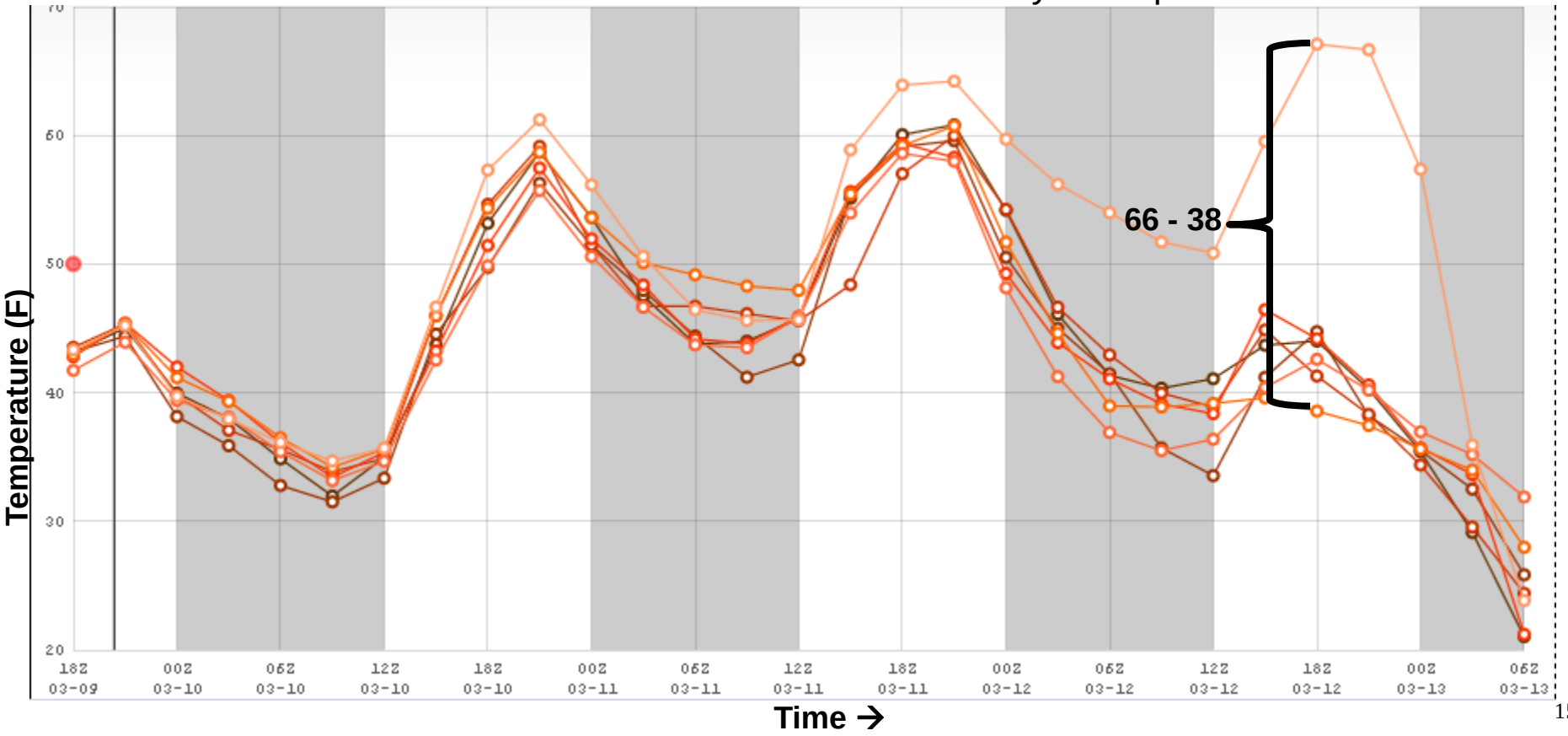


Temperature Prediction

Temperature Forecast for DC on March 12th

MODEL C

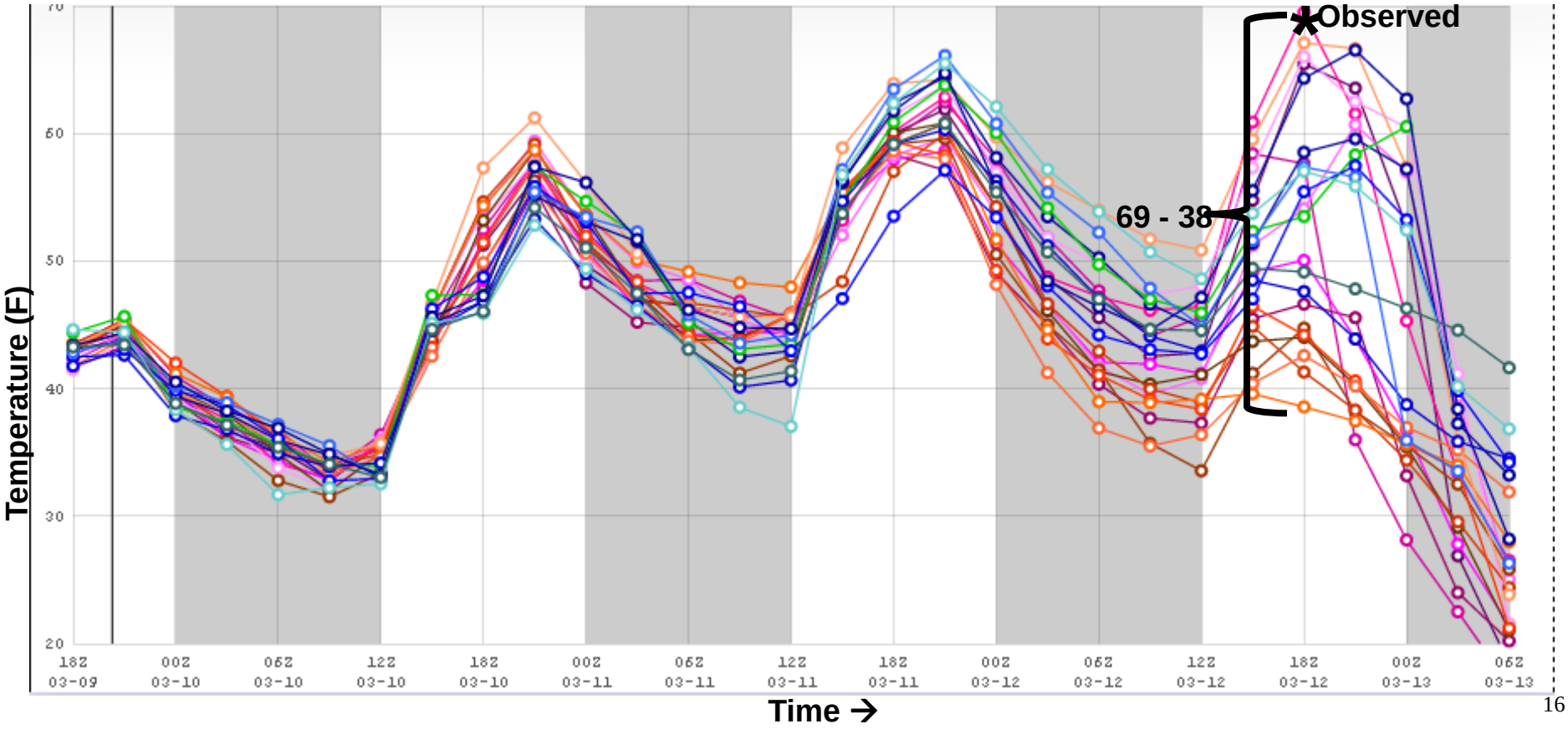
Slightly different:
-Initial conditions
-Physics representations



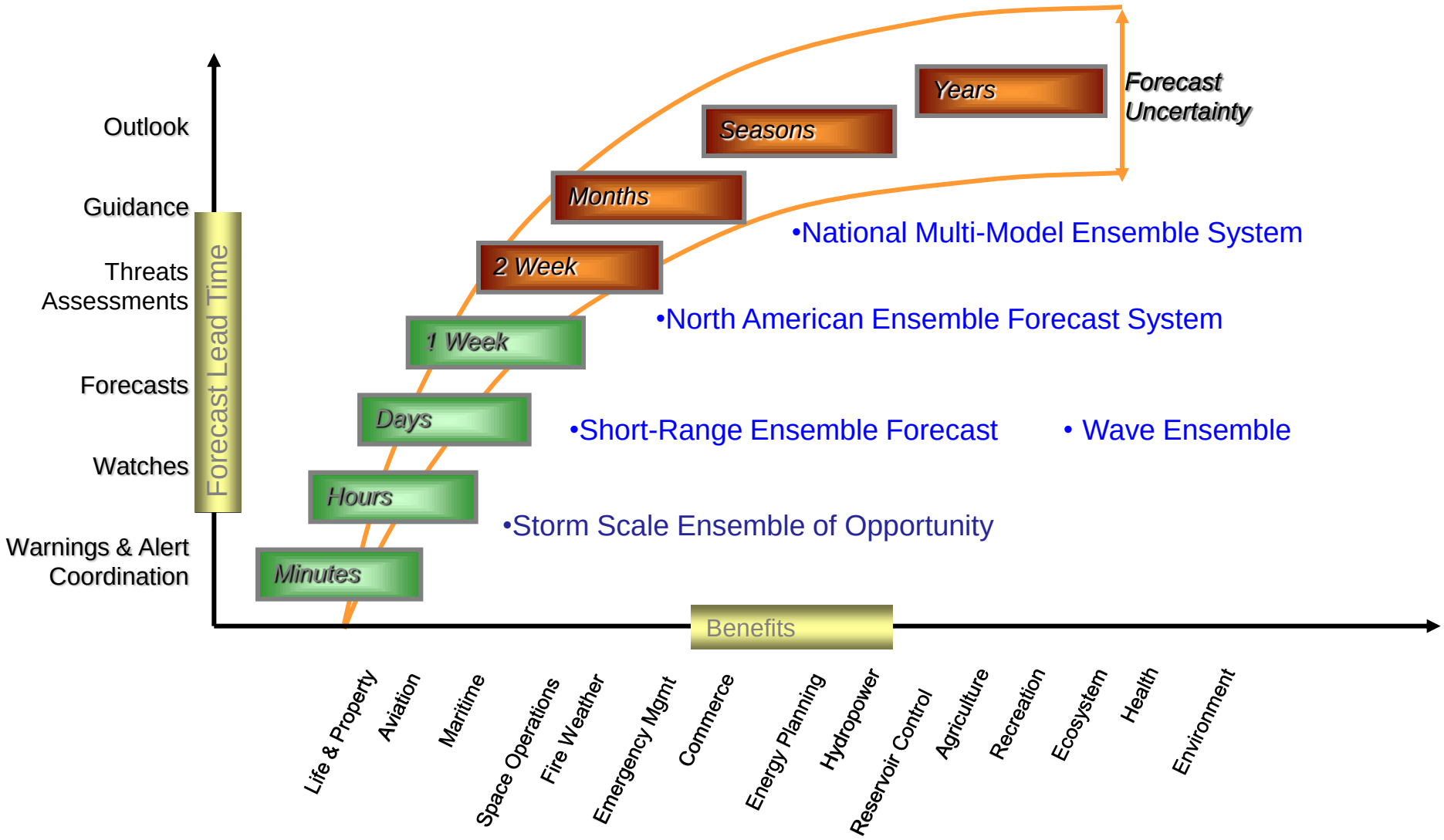
Temperature Prediction

Temperature Forecast for DC on March 12th

MODEL A+B+C

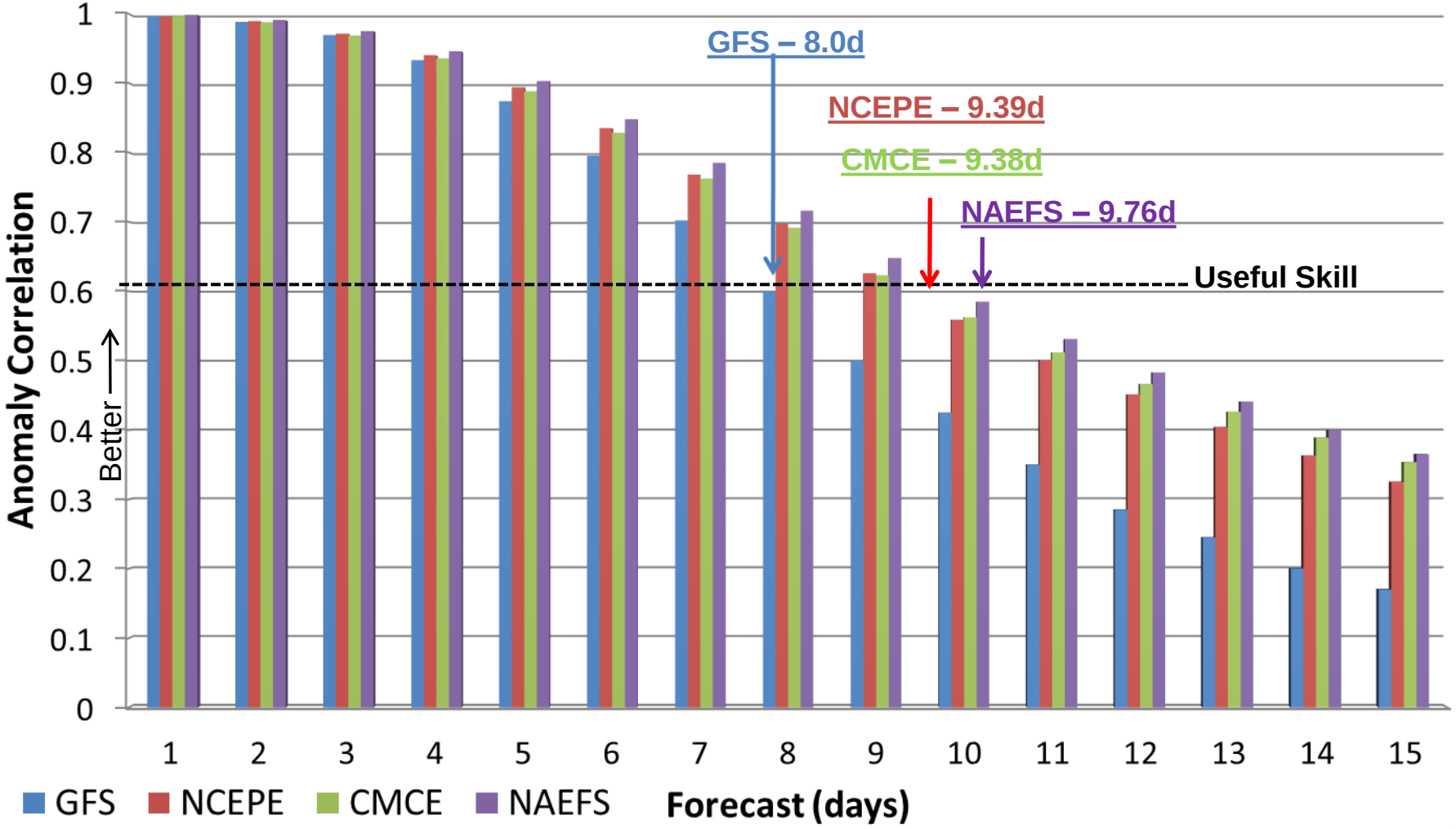


Suite of NOAA Operational Ensemble Systems



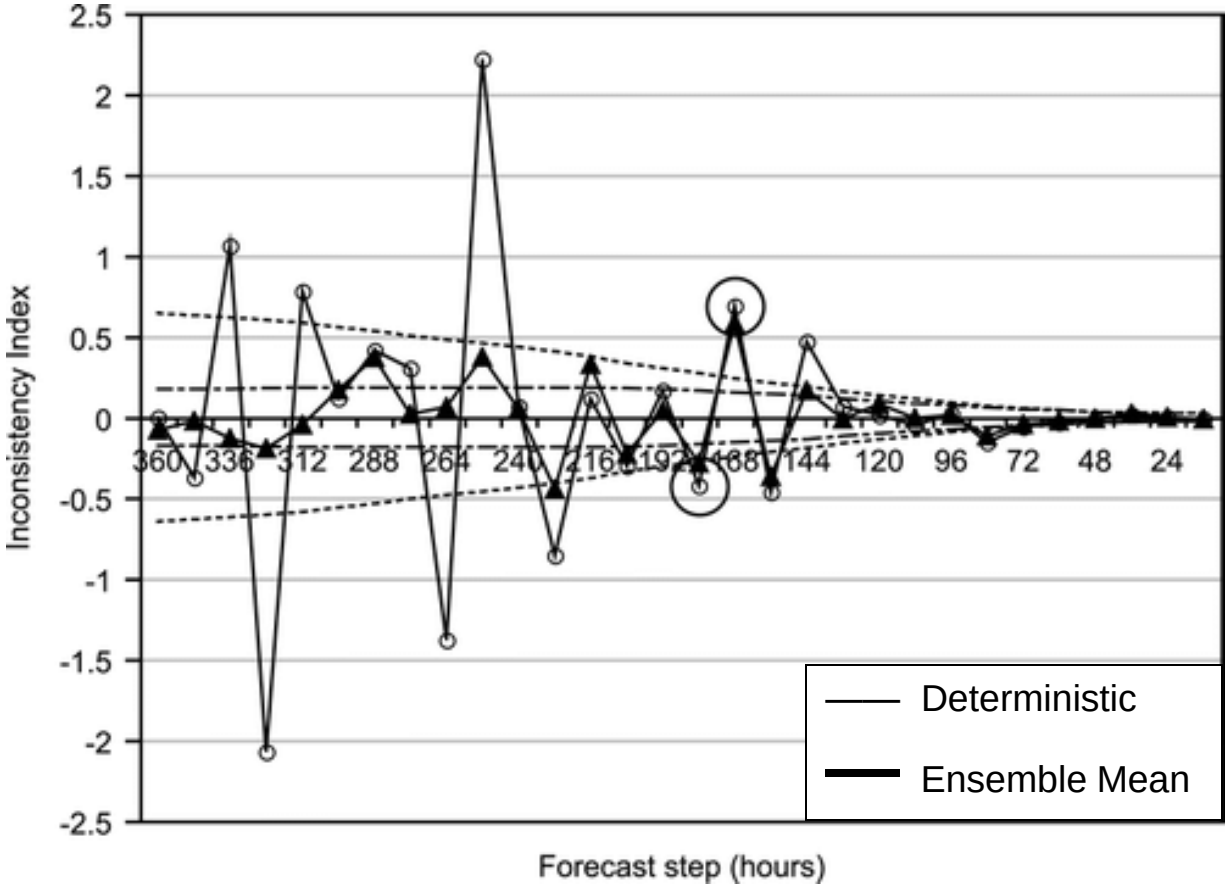
Are Ensembles Accurate?

Multi-model ensemble adds ~2 days of skill over determinstic



Are Ensembles Consistent?

‘Inconsistency Index’ (Zsoter et al. 2009)



Comparison of consistency between ECMWF ensemble control member and ensemble mean forecasts of 500 mb height valid at 1200 UTC 23 Feb 2008.

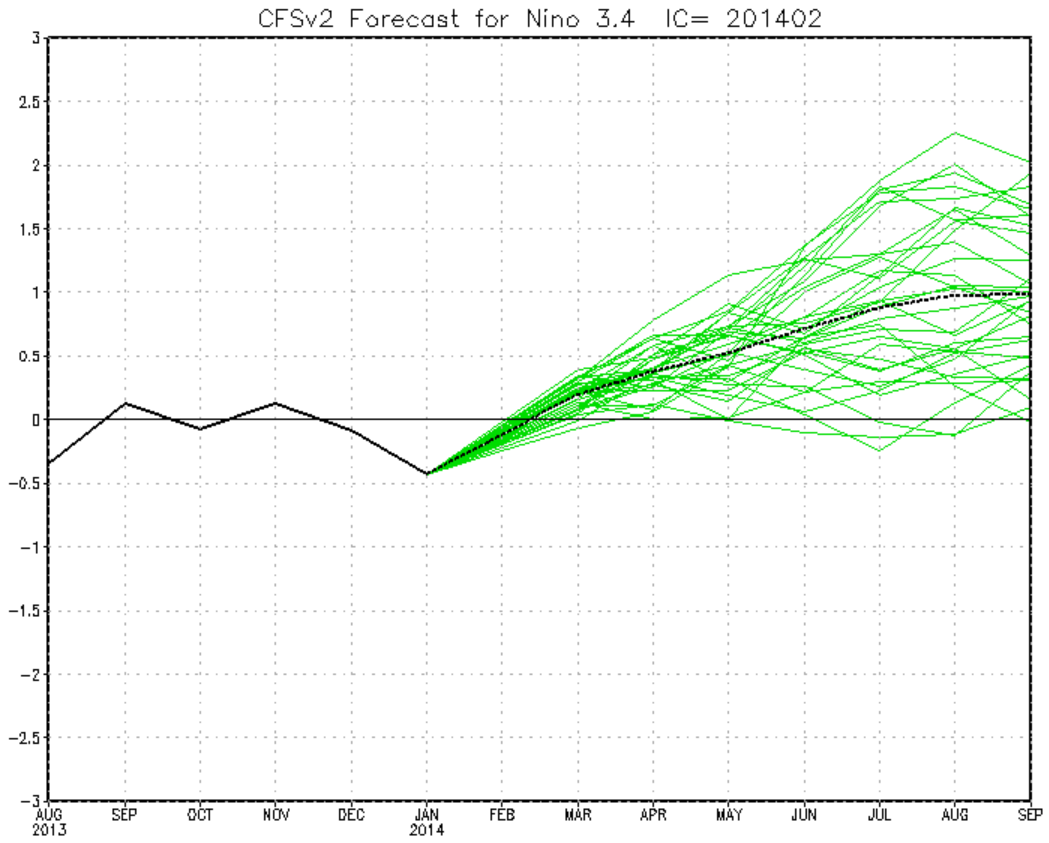
Ensemble mean forecast provides more consistent forecast than single model forecast

Inconsistency Index = Normalized difference of consecutive forecasts

Uses from the Forecaster Perspective

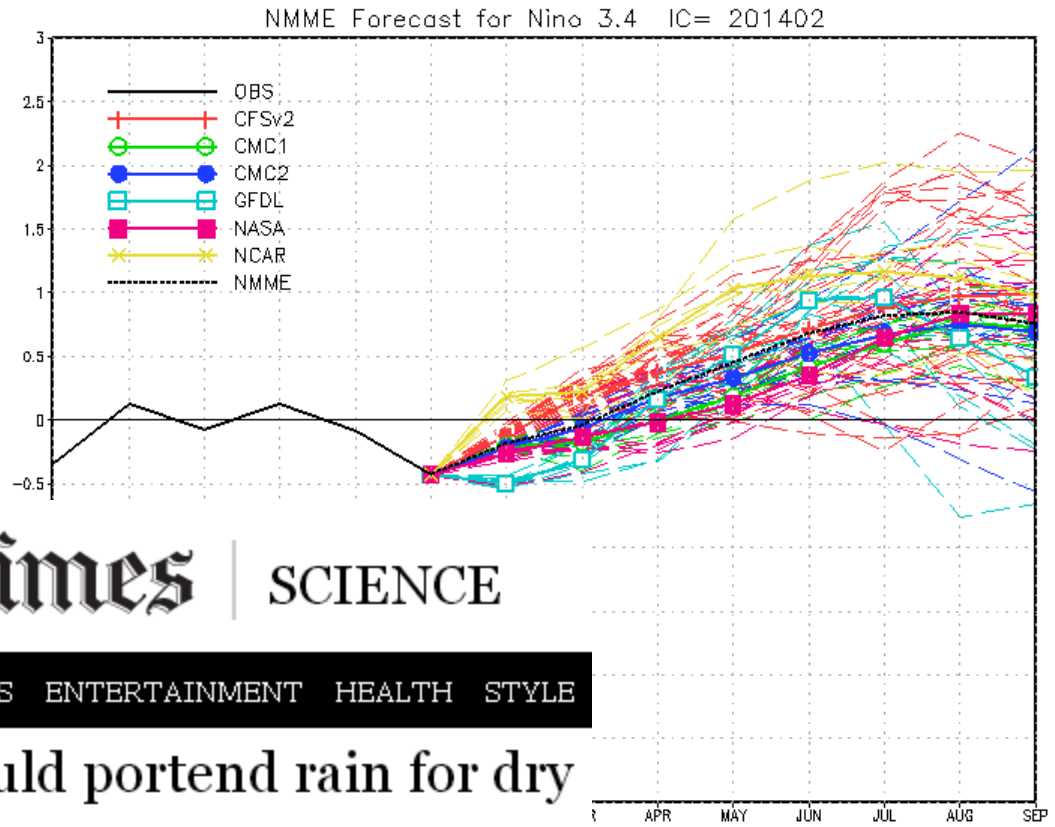
El Nino Prediction

Slightly different:
-Initial conditions
-Physics representations



El Nino Prediction

Slightly different:
-Initial conditions
-Physics representations
-Models



Los Angeles Times | SCIENCE

LOCAL U.S. WORLD BUSINESS SPORTS ENTERTAINMENT HEALTH STYLE

El Nino watch issued; could portend rain for dry California

By Tony Barboza

March 6, 2014 | 9:49 a.m.

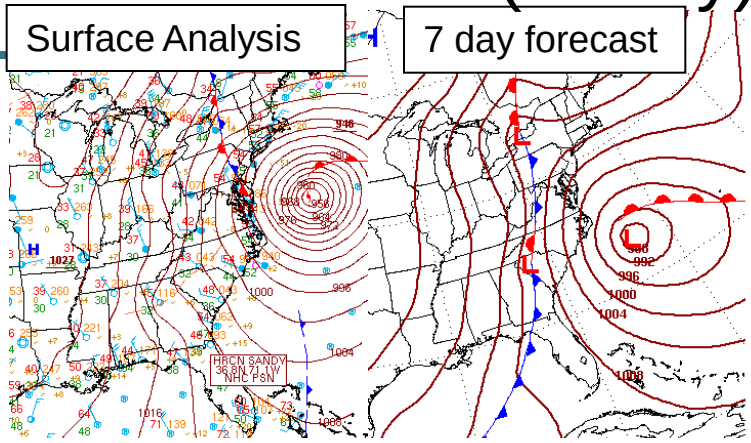
The National Oceanic and Atmospheric Administration's Climate Prediction Center activated its alert system on Thursday to issue an El Niño watch.

Hurricane Prediction

(Sandy)

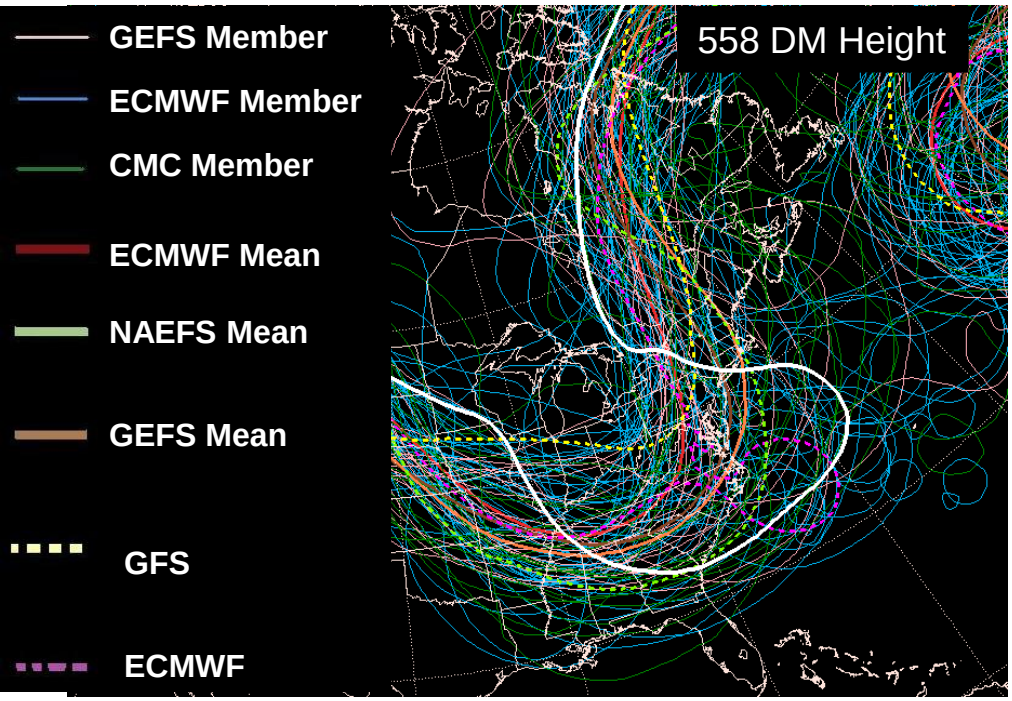
Surface Analysis

7 day forecast



12Z Oct 29, 2012

247 nm Displacement



FOR NOW, HAVE KEPT THE INCREASINGLY HYBRID CYCLONE OFF THE EAST COAST, THOUGH NOT AS FAR OUT TO SEA AS THE GFS AND GEFS MEMBERS.

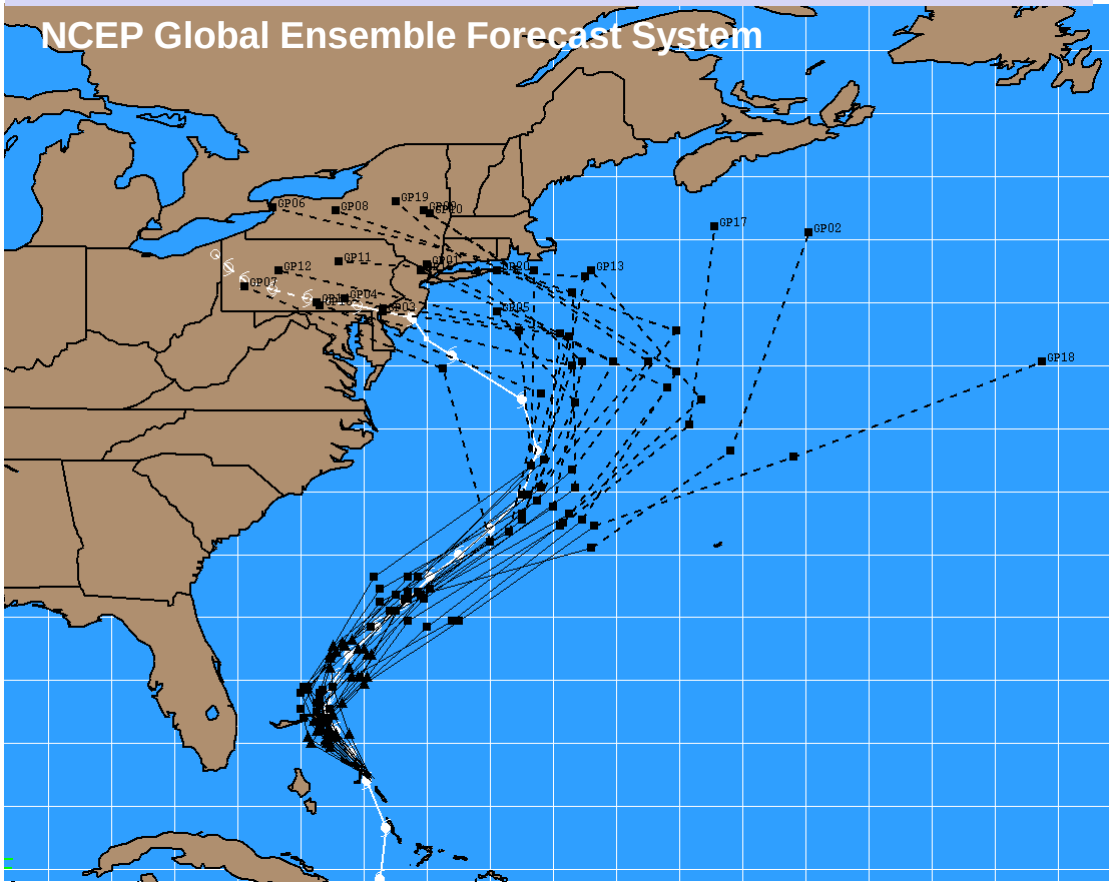
CONSIDERING THE WILDLY DIVERSE DETERMINISTIC SOLUTIONS AND ENSEMBLE MEMBERS…THAT SEEMS TO HAVE BEEN A SAFE BET.

CISCO

Hurricane Prediction
(Sandy)

Slightly different:
-Initial Conditions
-Physics Represent.

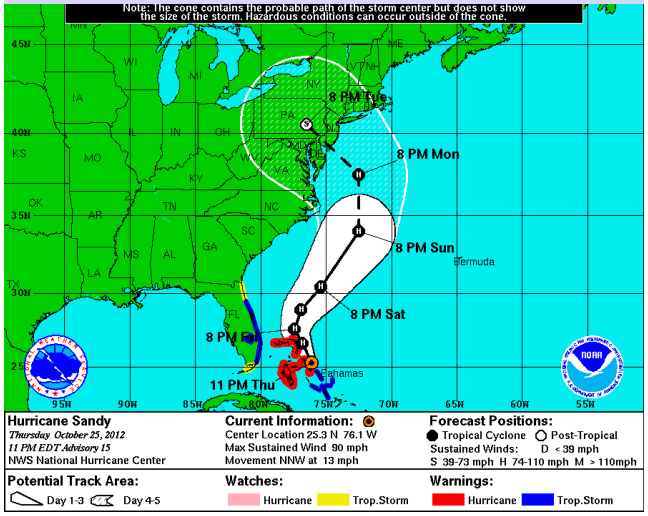
Forecast initialized 4 days prior to Landfall



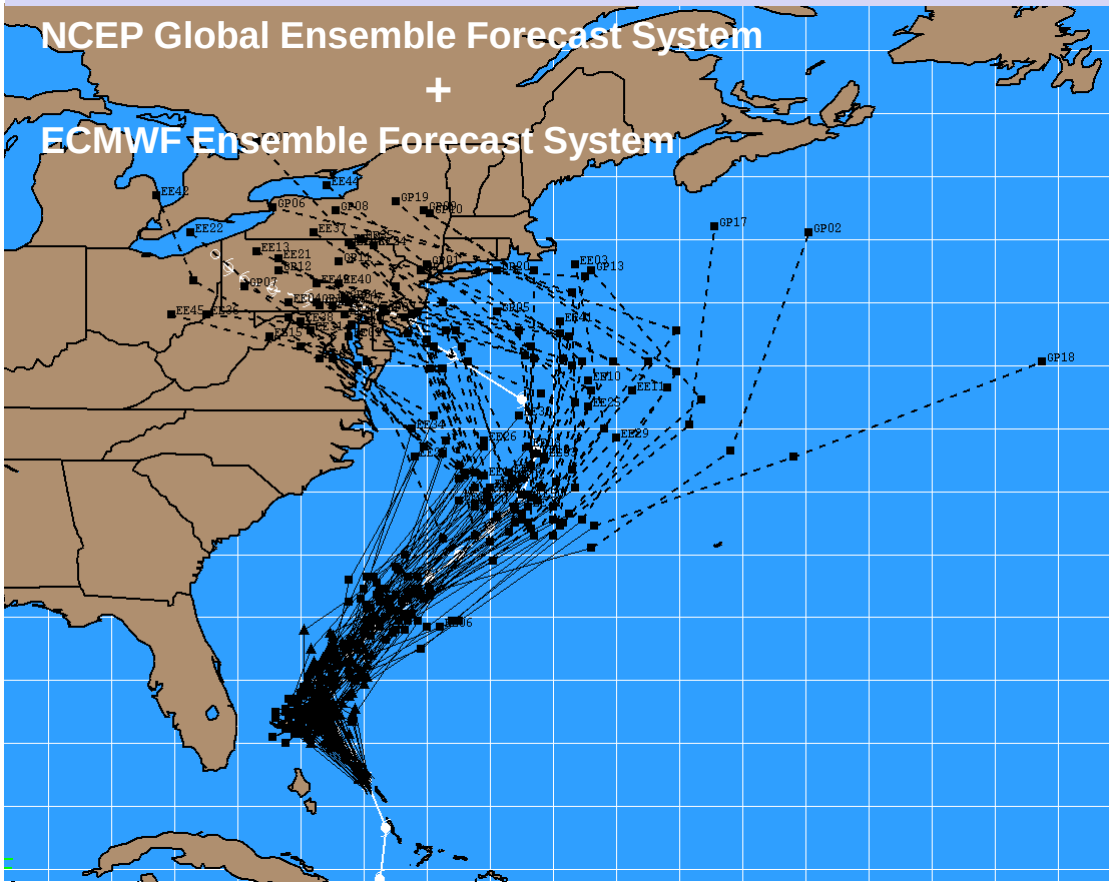
Hurricane Prediction
(Sandy)

Slightly different:
-Initial Conditions
-Physics Represent.
-Models

Used in Official Forecast



Forecast initialized 4 days prior to Landfall



Flood Prediction

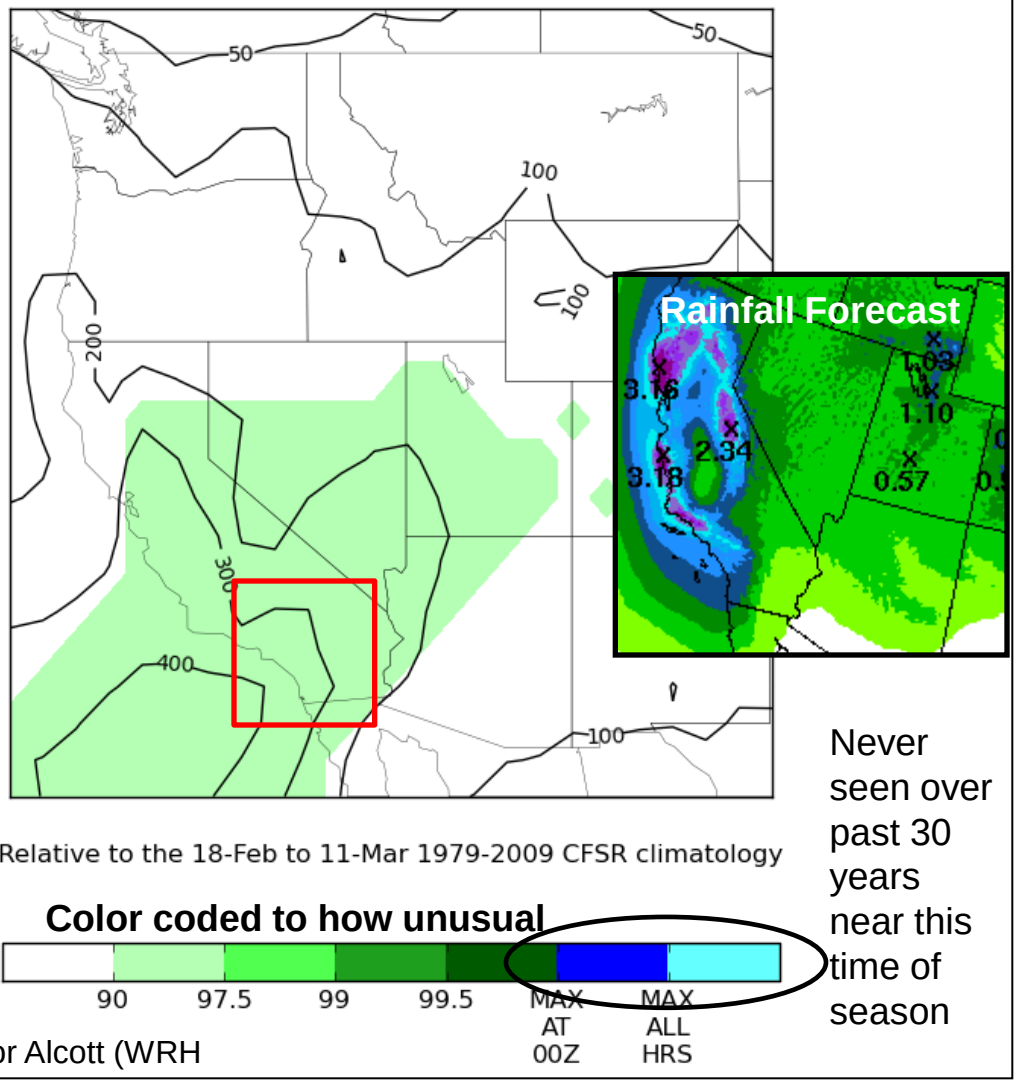
- Assess variables associated with heavy rain
- Compare today's multi-model ensemble mean forecast to a 30 year climatology to determine:
  - **How unusual** (members must show an unusual feature relative to climatology)
  - **How confident** (many members must show this feature at the same time & location)
- Display as situational awareness dashboard

7 Day NAEFS Forecast

CWA SGX Table Feb 22, 2014 00Z Run

Forecast Hour			Z	T	U	V	WSP	SLP	Q	PW	IVT
6	Sat 22nd	06Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
12		12Z	AVG	90	AVG	AVG	AVG	10	10	AVG	AVG
18		18Z	10	AVG	AVG	AVG	AVG	10	10	AVG	AVG
24	Sun 23rd	00Z	10	AVG	AVG	AVG	AVG	10	90	AVG	AVG
30		06Z	10	AVG	AVG	AVG	AVG	10	90	AVG	AVG
36		12Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
42		18Z	AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
48	Mon 24th	00Z	AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
54		06Z	AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
60		12Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
66		18Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
72	Tue 25th	00Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
78		06Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
84		12Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
90		18Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
96	Wed 26th	00Z	AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
102		06Z	AVG	90	AVG	AVG	AVG	AVG	90	90	AVG
108		12Z	AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
114		18Z	AVG	90	90	AVG	AVG	AVG	90	90	AVG
120	Thu 27th	00Z	90	90	90	AVG	90	AVG	90	90	90
126		06Z	90	90	90	AVG	90	AVG	90	90	90
132		12Z	90	90	90	AVG	90	AVG	90	AVG	90
138		18Z	90	AVG	90	AVG	90	AVG	90	AVG	AVG
144	Fri 28th	00Z	90	AVG	97.5	AVG	90	AVG	90	AVG	AVG
150		06Z	90	AVG	90	AVG	90	AVG	90	AVG	AVG
156		12Z	AVG	AVG	90	90	90	AVG	90	AVG	90
162		18Z	AVG	AVG	90	97.5	90	10	90	90	90
168		00Z	10	AVG	90	97.5	90	10	90	90	90
174	Sat 1st	06Z	10	AVG	90	97.5	90	10	90	90	90
180		12Z	10	AVG	90	90	90	10	90	90	90
186		18Z	AVG	AVG	90	AVG	AVG	AVG	90	AVG	90
192	Sun 2nd	00Z	AVG	AVG	90	AVG	AVG	AVG	90	AVG	AVG
198		06Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
204		12Z	AVG	10	AVG	10	AVG	AVG	90	AVG	AVG
210		18Z	AVG	AVG	AVG	10	AVG	AVG	AVG	AVG	AVG
216	Mon 3rd	00Z	AVG	AVG	AVG	10	AVG	AVG	90	AVG	AVG
222		06Z	AVG	90	AVG	10	AVG	90	90	AVG	AVG
228		12Z	90	AVG	AVG	10	AVG	90	90	AVG	AVG
234		18Z	90	90	AVG	AVG	AVG	AVG	90	AVG	AVG
240	Tue 4th	00Z	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG	AVG

Variables



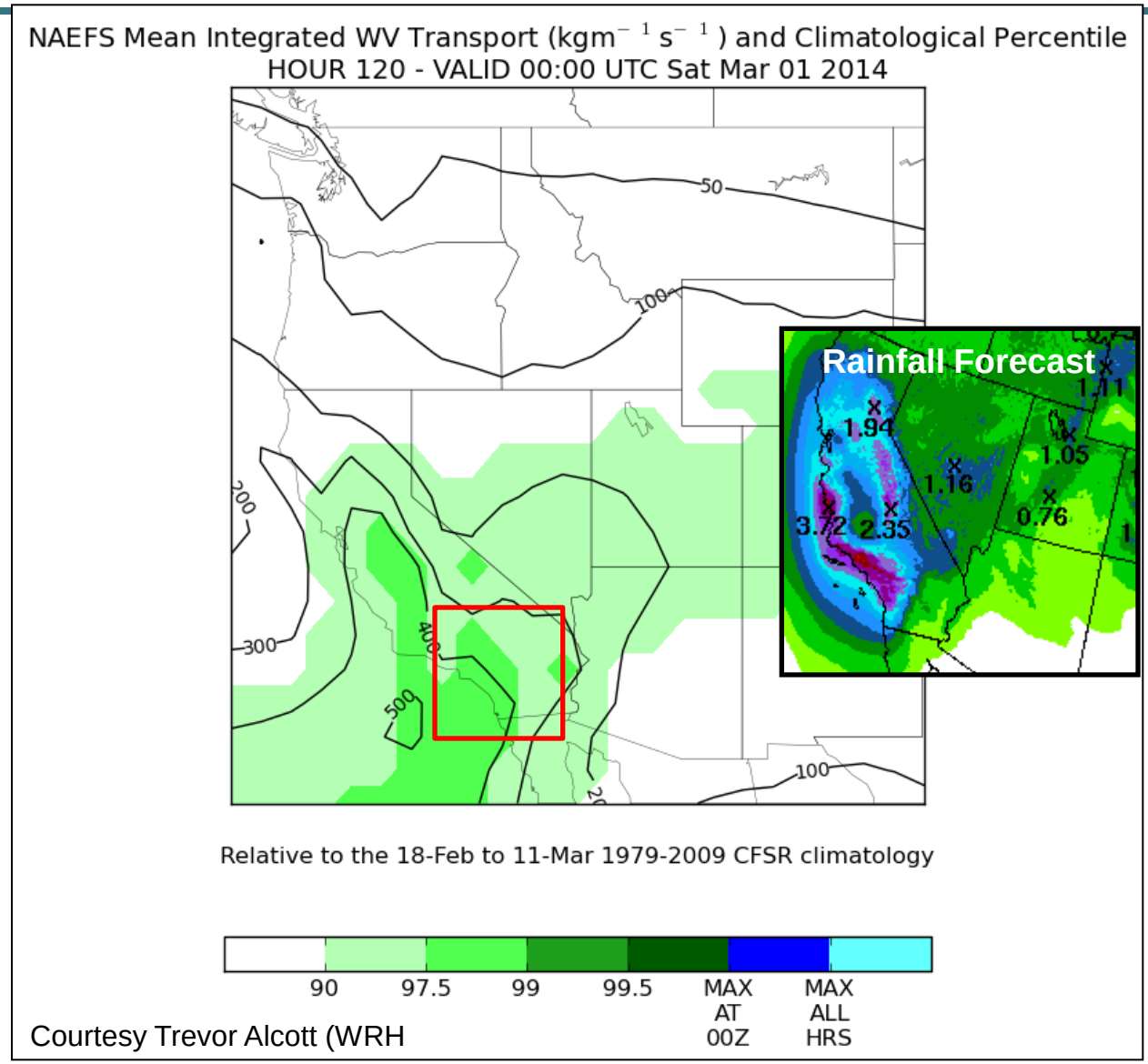
Never seen over past 30 years near this time of season

Courtesy Trevor Alcott (WRH

5 Day NAEFS Forecast

CWA SGX Table Feb 24, 2014 00Z Run

Forecast Hour			Z	T	U	V	WSP	SLP	Q	PW	IVT
6	Mon 24th	06Z	AVG	90	AVG	AVG	AVG	AVG	2.5	AVG	AVG
12		12Z	AVG	90	AVG	AVG	AVG	AVG	2.5	AVG	AVG
18		18Z	AVG	90	AVG	AVG	AVG	AVG	10	AVG	AVG
24	Tue 25th	00Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
30		06Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
36		12Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
42		18Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
48	Wed 26th	00Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
54		06Z	AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
60		12Z	AVG	97.5	AVG	AVG	AVG	AVG	90	AVG	AVG
66		18Z	90	90	90	AVG	AVG	AVG	90	90	AVG
72	Thu 27th	00Z	90	90	90	90	90	AVG	90	90	90
78		06Z	90	97.5	90	90	90	AVG	97.5	90	90
84		12Z	90	97.5	90	AVG	90	AVG	90	90	90
90		18Z	90	90	97.5	AVG	90	AVG	90	AVG	90
96	Fri 28th	00Z	90	90	97.5	AVG	97.5	AVG	AVG	AVG	AVG
102		06Z	90	AVG	97.5	90	97.5	AVG	90	AVG	AVG
108		12Z	AVG	AVG	90	97.5	90	AVG	90	90	90
114		18Z	10	AVG	90	99.5	90	10	90	90	97.5
120		00Z	10	AVG	90	99.5	97.5	10	90	90	97.5
126	Sat 1st	06Z	10	90	90	99	97.5	10	90	90	97.5
132		12Z	10	90	90	90	90	10	90	90	90
138		18Z	10	90	90	90	90	10	90	90	90
144	Sun 2nd	00Z	AVG	AVG	90	AVG	90	AVG	90	AVG	90
150		06Z	AVG	AVG	90	AVG	AVG	AVG	90	AVG	AVG
156		12Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
162		18Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
168	Mon 3rd	00Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
174		06Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
180		12Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
186		18Z	AVG	AVG	AVG	AVG	AVG	AVG	AVG	AVG	AVG
192	Tue 4th	00Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
198		06Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
204		12Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
210		18Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
216	Wed 5th	00Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
222		06Z	AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
228		12Z	AVG	AVG	AVG	AVG	AVG	AVG	AVG	AVG	AVG
234		18Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
240	Thu 6th	00Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG

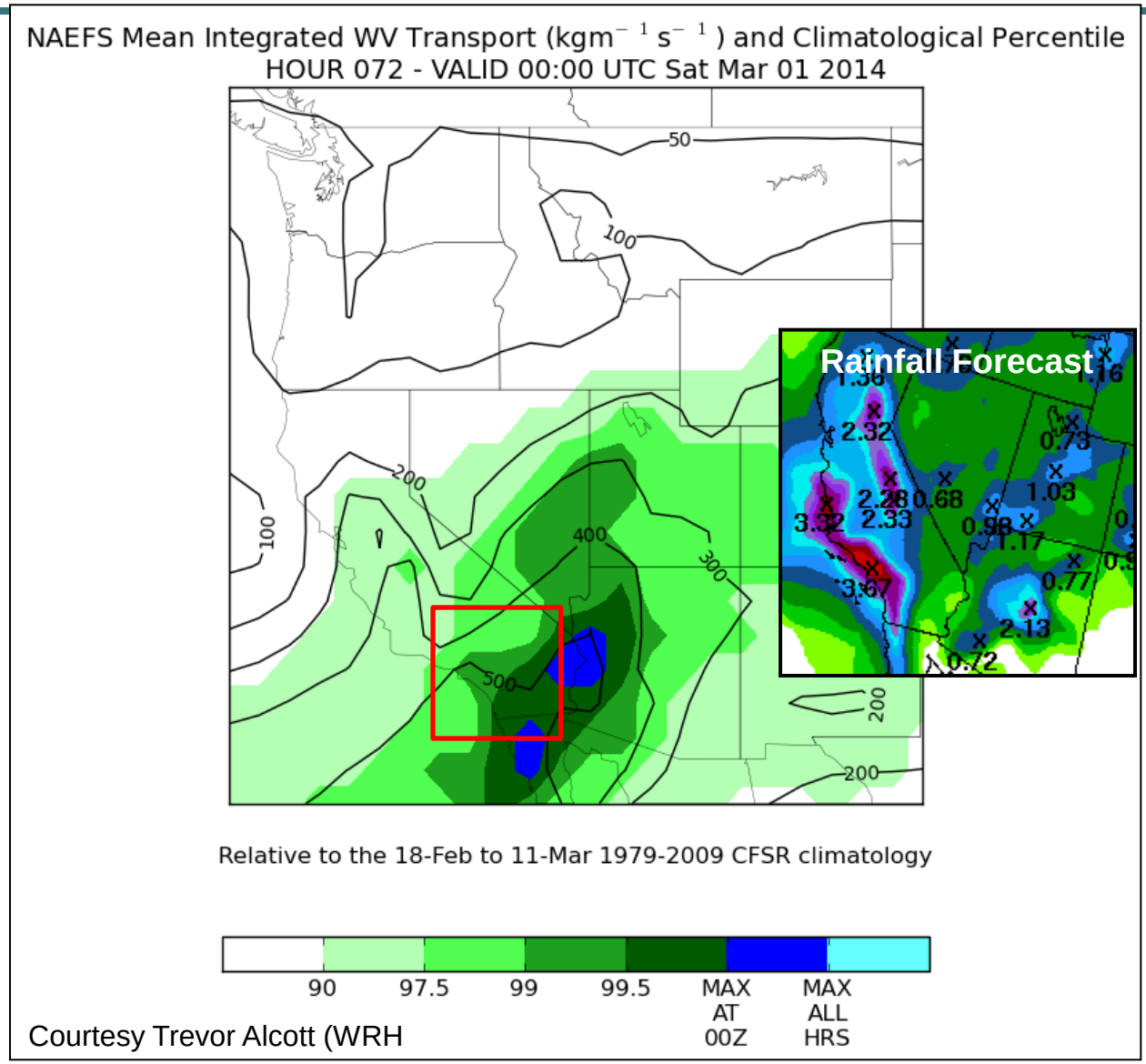


Courtesy Trevor Alcott (WRH

3 Day NAEFS Forecast

CWA SGX Table Feb 26, 2014 00Z Run

Forecast Hour				Z	T	U	V	WSP	SLP	Q	PW	IVT
6	Wed 26th	06Z		AVG	97.5	AVG	90	AVG	AVG	97.5	90	AVG
12		12Z		AVG	97.5	AVG	AVG	AVG	AVG	90	90	AVG
18		18Z		AVG	90	90	AVG	AVG	AVG	90	90	90
24	Thu 27th	00Z		AVG	90	90	AVG	90	AVG	90	90	90
30		06Z		90	90	97.5	90	90	AVG	99	97.5	90
36		12Z		90	90	97.5	AVG	90	AVG	99	97.5	90
42		18Z		90	97.5	97.5	AVG	90	AVG	99	97.5	90
48	Fri 28th	00Z		90	90	99	AVG	97.5	AVG	97.5	90	90
54		06Z		10	AVG	97.5	90	97.5	10	99	97.5	97.5
60		12Z		2.5	90	90	99.5	99	2.5	99.5	99	99.5
66		18Z		2.5	90	97.5	99.5	99.5	2.5	99	99.5	MAX
72		00Z		2.5	AVG	97.5	99.5	99.5	1	99.5	99	MAX
78	Sat 1st	06Z		2.5	90	90	99	99	1	99.5	97.5	99
84		12Z		2.5	90	90	97.5	97.5	2.5	99	90	97.5
90		18Z		10	90	90	97.5	90	10	97.5	90	90
96		00Z		10	90	90	90	AVG	10	97.5	90	90
102	Sun 2nd	06Z		AVG	AVG	AVG	AVG	AVG	AVG	97.5	90	AVG
108		12Z		AVG	AVG	AVG	AVG	AVG	AVG	90	90	AVG
114		18Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
120		00Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
126	Mon 3rd	06Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
132		12Z		AVG	AVG	AVG	10	AVG	AVG	90	AVG	AVG
138		18Z		AVG	AVG	AVG	10	AVG	AVG	90	AVG	AVG
144	Tue 4th	00Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
150		06Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
156		12Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
162		18Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
168	Wed 5th	00Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
174		06Z		AVG	AVG	AVG	AVG	AVG	AVG	90	AVG	AVG
180		12Z		AVG	AVG	AVG	10	AVG	AVG	AVG	AVG	AVG
186		18Z		AVG	AVG	AVG	10	AVG	AVG	AVG	AVG	AVG
192	Thu 6th	00Z		AVG	AVG	AVG	AVG	AVG	AVG	AVG	AVG	AVG
198		06Z		AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
204		12Z		AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
210		18Z		AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
216	Fri 7th	00Z		AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
222		06Z		AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
228		12Z		AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
234		18Z		AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
240	Sat 8th	00Z		AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG



Courtesy Trevor Alcott (WRH

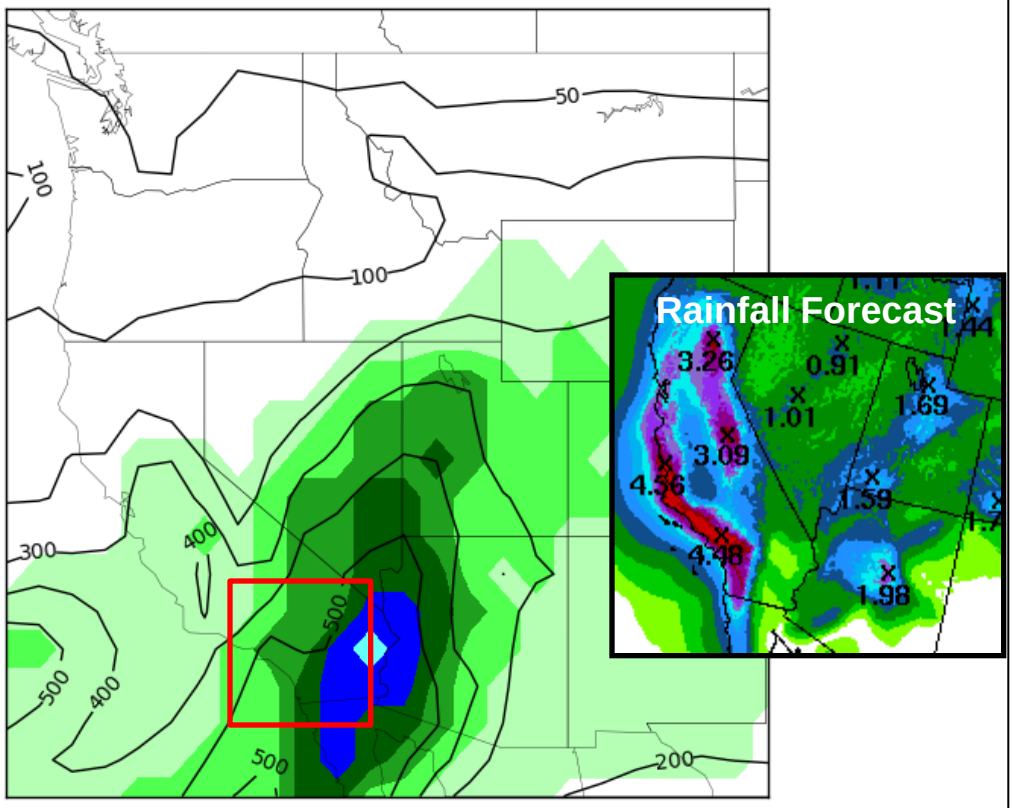
1.5 Day NAEFS Forecast

CWA SGX Table Feb 27, 2014 12Z Run

Forecast Hour

			Z	T	U	V	WSP	SLP	Q	PW	IVT
6	Thu 27th	18Z	90	90	99.5	AVG	97.5	10	99	90	90
12		00Z	90	90	99	AVG	97.5	AVG	99	90	90
18	Fri 28th	06Z	10	AVG	97.5	97.5	97.5	10	99	99	99
24		12Z	2.5	90	90	MAX	99	2.5	MAX	99	MAX
30		18Z	2.5	90	97.5	MAX	MAX	2.5	MAX	MAX	MAX
36		00Z	2.5	90	97.5	MAX	MAX	1	MAX	99.5	MAX
42	Sat 1st	06Z	2.5	10	90	99.5	99	2.5	99.5	97.5	99
48		12Z	2.5	90	90	97.5	97.5	2.5	99	90	97.5
54		18Z	2.5	90	90	97.5	90	2.5	97.5	90	90
60		00Z	10	90	90	90	90	10	97.5	90	90
66	Sun 2nd	06Z	10	AVG	90	AVG	AVG	10	97.5	90	90
72		12Z	AVG	AVG	AVG	AVG	AVG	AVG	90	90	AVG
78		18Z	AVG	AVG	AVG	10	AVG	AVG	97.5	AVG	AVG
84		00Z	AVG	AVG	AVG	10	AVG	AVG	99	AVG	AVG
90	Mon 3rd	06Z	AVG	AVG	AVG	10	AVG	AVG	97.5	AVG	AVG
96		12Z	AVG	90	90	10	90	AVG	90	AVG	AVG
102		18Z	90	90	90	10	90	AVG	90	90	AVG
108		00Z	90	90	90	10	90	AVG	97.5	90	90
114	Tue 4th	06Z	90	90	90	10	90	AVG	90	90	90
120		12Z	90	90	90	10	90	AVG	90	90	90
126		18Z	90	90	90	10	90	AVG	90	AVG	AVG
132		00Z	90	90	90	10	90	AVG	90	AVG	AVG
138	Wed 5th	06Z	97.5	90	90	10	90	AVG	90	AVG	AVG
144		12Z	97.5	90	90	10	90	AVG	90	AVG	AVG
150		18Z	97.5	90	AVG	10	AVG	AVG	90	AVG	AVG
156		00Z	97.5	90	90	AVG	AVG	AVG	90	AVG	AVG
162	Thu 6th	06Z	97.5	90	90	AVG	AVG	AVG	90	90	AVG
168		12Z	90	90	90	AVG	AVG	AVG	90	AVG	AVG
174		18Z	90	90	90	AVG	AVG	AVG	90	AVG	AVG
180		00Z	90	90	90	10	AVG	AVG	90	AVG	AVG
186	Fri 7th	06Z	AVG	90	AVG	10	AVG	AVG	90	AVG	AVG
192		12Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
198		18Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
204		00Z	AVG	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
210	Sat 8th	06Z	AVG	90	AVG	AVG	AVG	AVG	90	AVG	AVG
216		12Z	90	97.5	AVG	AVG	AVG	AVG	AVG	AVG	AVG
222		18Z	90	97.5	AVG	AVG	AVG	AVG	AVG	AVG	AVG
228		00Z	90	90	AVG	AVG	AVG	AVG	AVG	AVG	AVG
234	Sun 9th	06Z	90	97.5	AVG	AVG	AVG	AVG	AVG	AVG	AVG
240		12Z	90	97.5	AVG	AVG	AVG	AVG	AVG	AVG	AVG

NAEFS Mean Integrated WV Transport ($kgm^{-1}s^{-1}$) and Climatological Percentile
HOUR 036 - VALID 00:00 UTC Sat Mar 01 2014



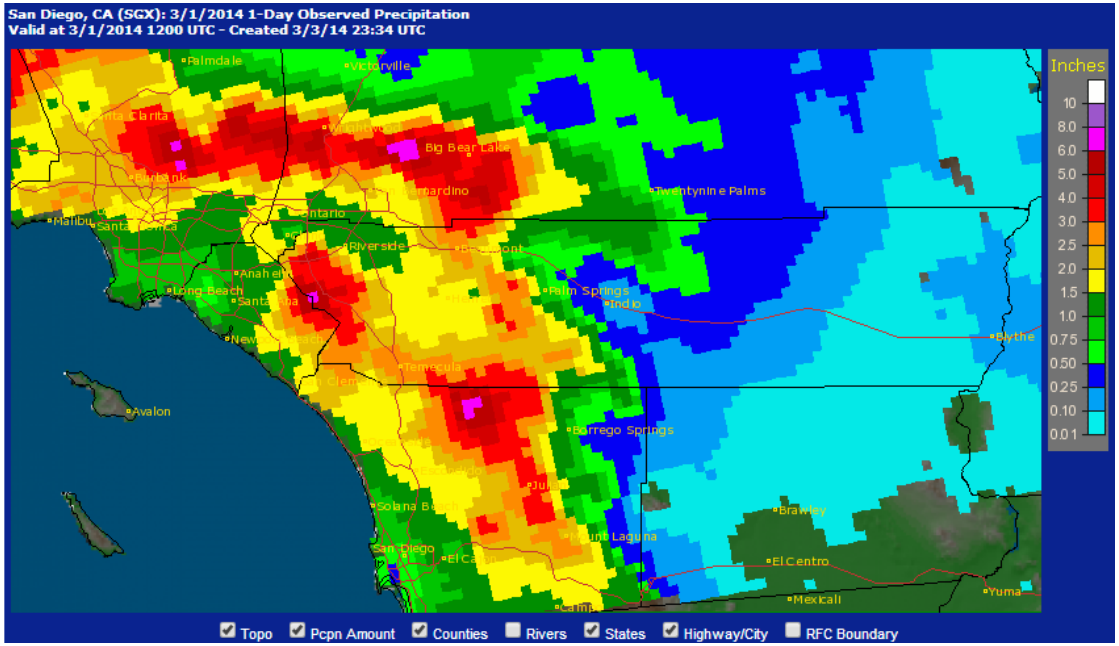
Relative to the 18-Feb to 11-Mar 1979-2009 CFSR climatology

90 | 97.5 | 99 | 99.5 | MAX AT 00Z | MAX ALL HRS

Courtesy Trevor Alcott (WRH

California Atmospheric River

Feb 27-March 2, 2014



Images courtesy Alex Tardy (SGX)

Severe Weather Prediction

Resolution Matters

Global models simulate bulk effects of a thunderstorm

Storm scale models explicitly simulate the updraft, downdraft, and cloud features

Storm Scale Ensemble of Opportunity

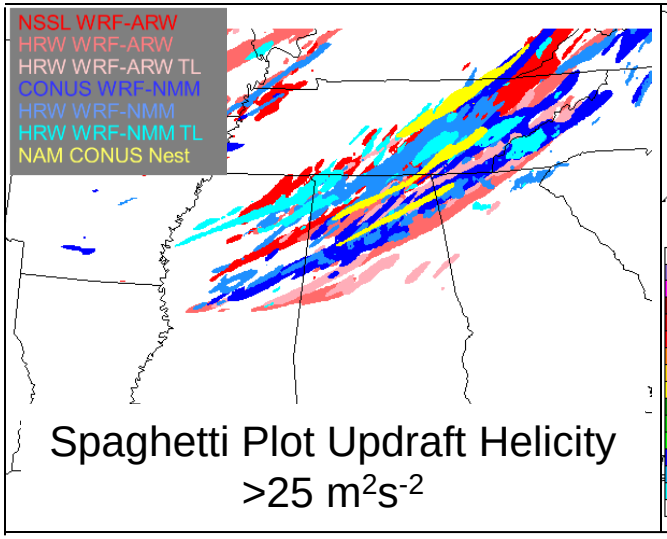
- 7 members (2 time-lagged) at ~ 4 km grid spacing
- Multi-model (ARW, WRF-NMM & NMM-B), multi-physics
- Predict storm scale features such as wind gusts, hail, and rotating updrafts

Severe Weather Prediction

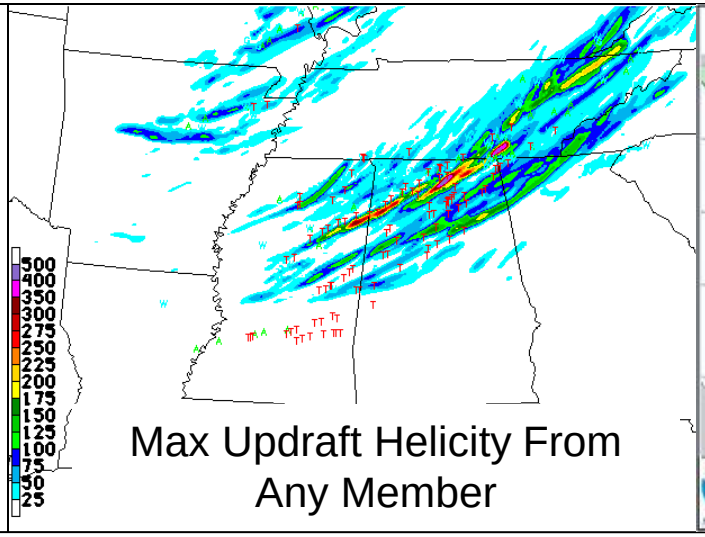
April 27, 2011

- Record tornado and fatality day
  - 208 Tornadoes, 30 Killer Tornadoes, 319 Deaths
  - 15 EF4 & EF5 Tornadoes
  - 235 Deaths in Alabama

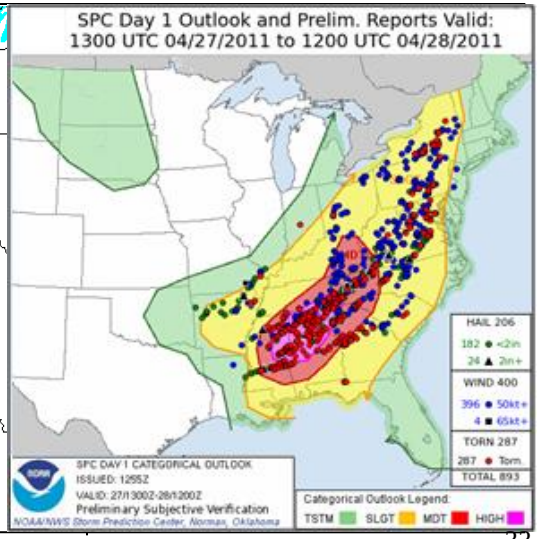
Storm Scale Ensemble shows long-track rotating updrafts → Accurate Forecast



Spaghetti Plot Updraft Helicity >25 m^2s^{-2}



Max Updraft Helicity From Any Member



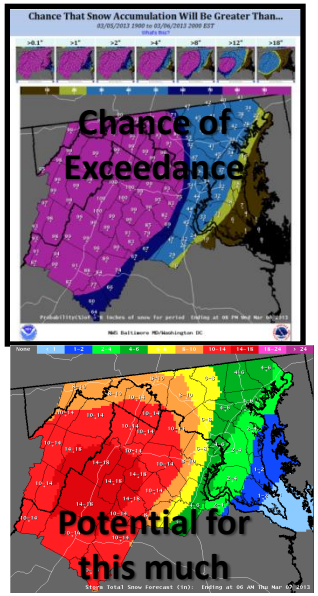
Uses from the Decision Maker Perspective

Communicating Impact
(Snowfall)

WFO Baltimore-Washington Pilot Project
IDSS in an Urban Environment

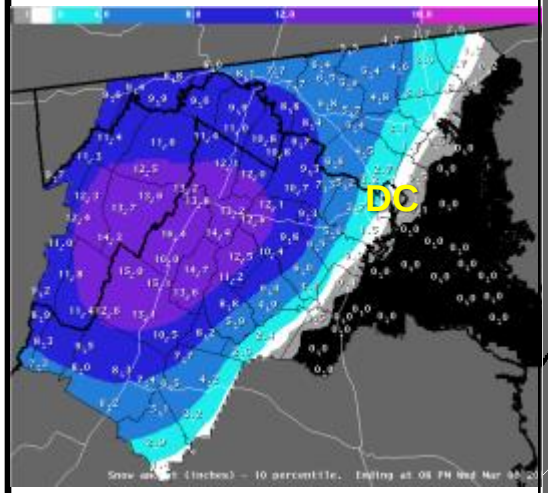
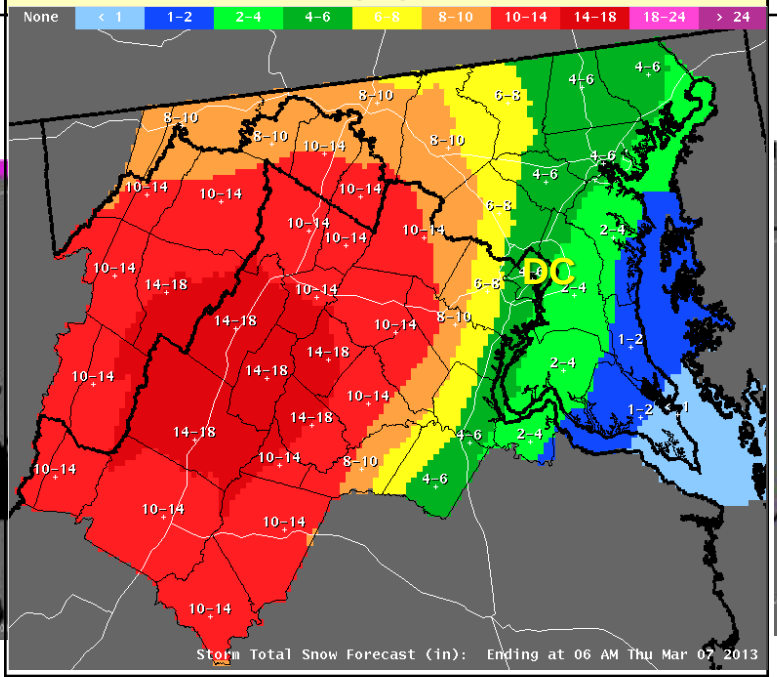
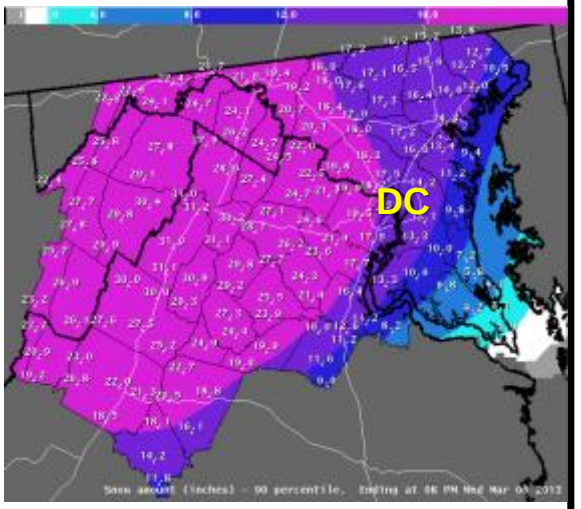
Create and communicate snowfall probability information for decision makers

Multi Model Ensemble + human influence
SREF
GEFS
ECMWF
GFS
NAM
Canadian



Communicating Impact
(Snowfall)

Provide a reasonable best / worst-case scenario

Minimum (1”)	Most Likely (5”)	Maximum (13”)
		
Expect at least this much	Official NWS Forecast	Potential for this much

Local Emergency Manager: **“This is one of the most important new initiatives from NWS we have seen for Emergency Managers in years.”**

Communicating Impact
(Aviation)

Risk of Event	>	Risk Tolerance	=	Take Action

Chance of Heavy Snow	Risk Tolerance	Action
45%	**40%**	**Cancel Flights**

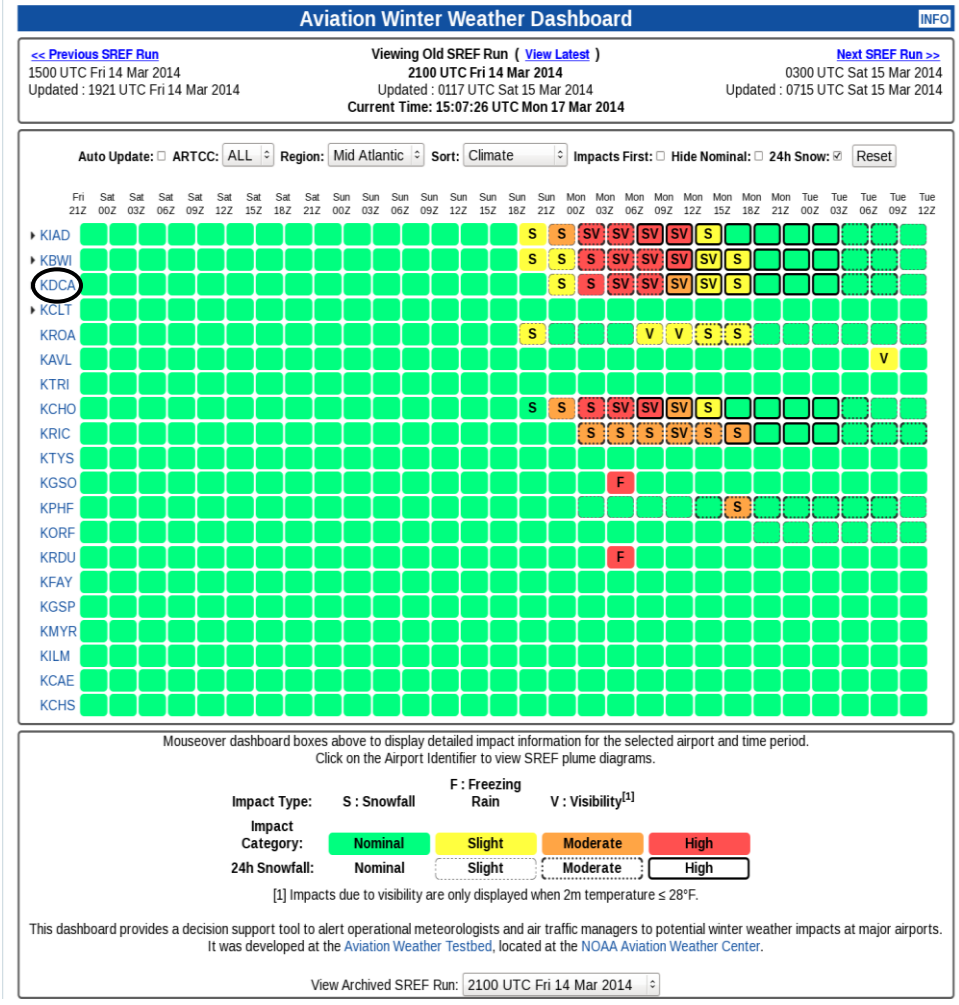
NWS worked with FAA and Industry to define impact thresholds

Criteria for DCA

Event	Slight Prob >40%	Modt Prob >40%	High Prob > 40%
3-h Snow	> 0.2”	> 0.75”	> 1.5”
24-h Snow	> 1”	> 2”	>6”
3-h Fz Rain		> 0.01”	> 0.05”
Visibility	< 3 mi	< 1 mi	< ½ mi

Communicating Impact
(Aviation)

3 Days Before



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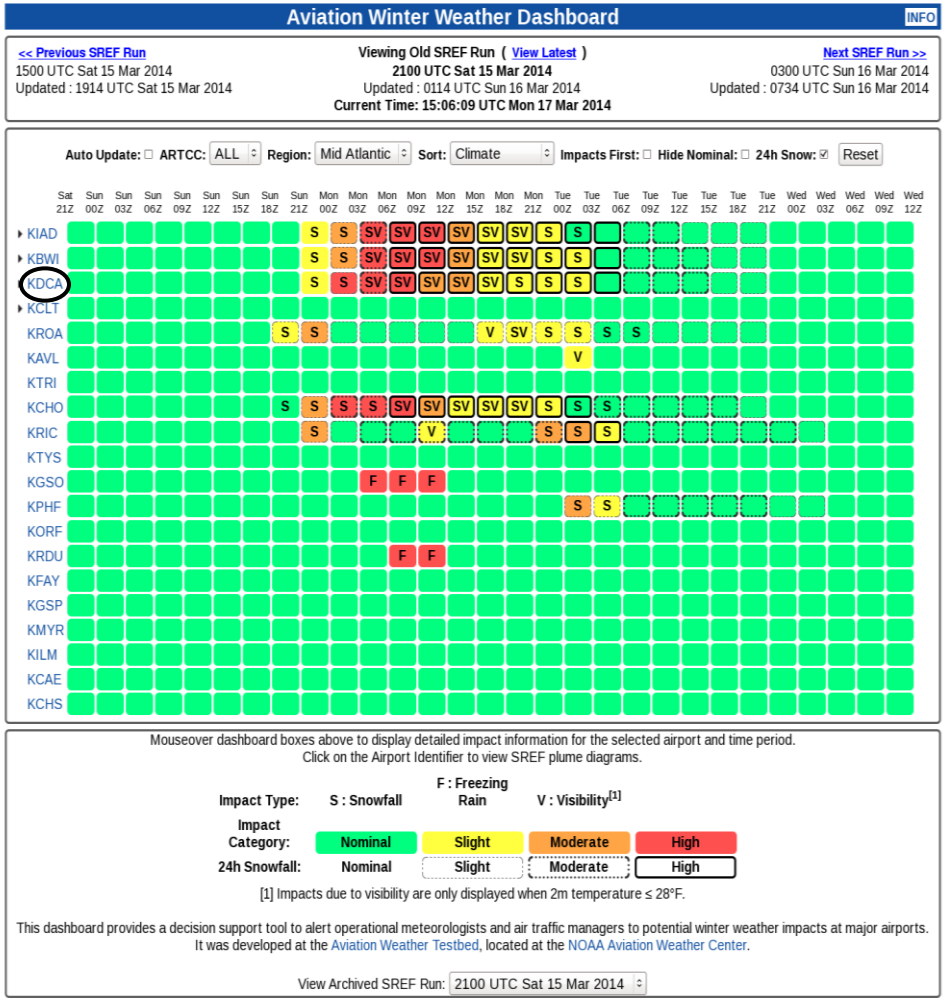
3-h Snow	> 0.2”	> 0.75”	> 1.5”
24-h Snow	> 1”	> 2”	>6”
3-h Fz Rain		> 0.01”	> 0.05”
Visibility	< 3 mi	< 1 mi	< ½ mi

Communicating Impact
(Aviation)

2 Days Before

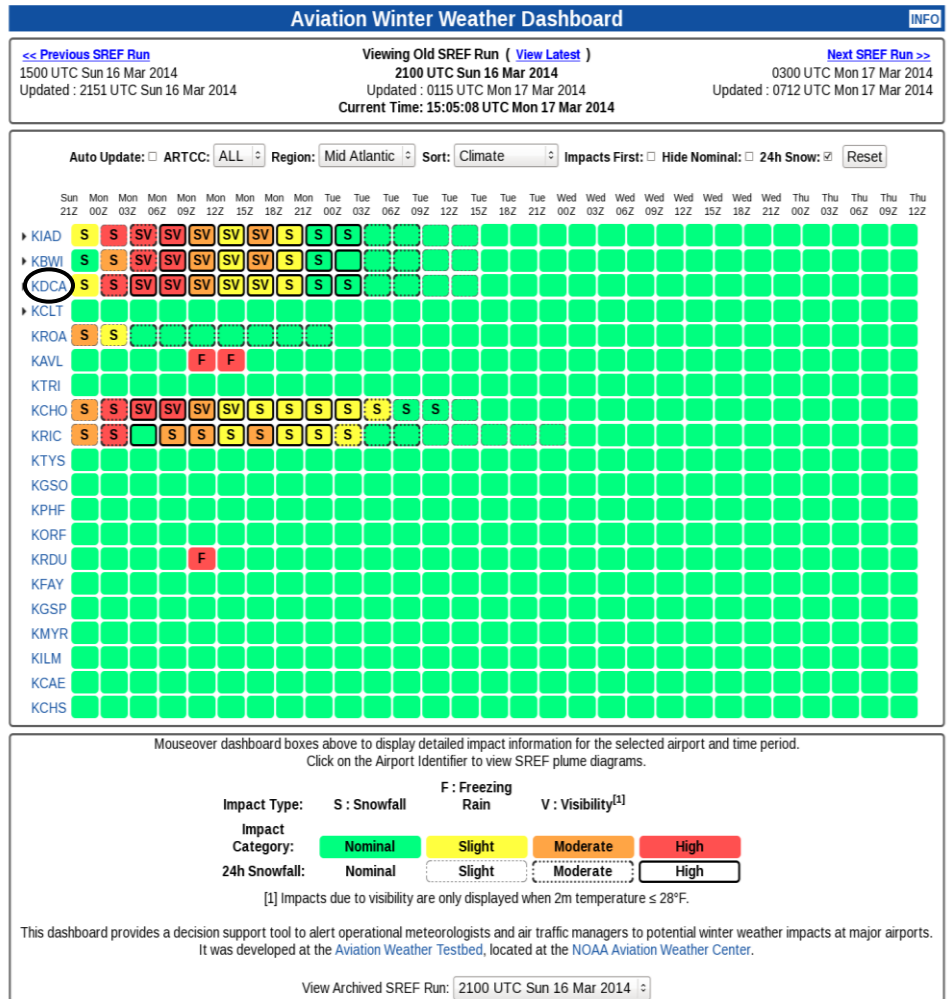


Criteria for DCA

Event	Slight Prob >40%	Modt Prob >40%	High Prob > 40%
3-h Snow	> 0.2”	> 0.75”	> 1.5”
24-h Snow	> 1”	> 2”	>6”
3-h Fz Rain		> 0.01”	> 0.05”
Visibility	< 3 mi	< 1 mi	< ½ mi

Communicating Impact
(Aviation)

1 Day Before



Criteria for DCA

Event	Slight Prob >40%	Modt Prob >40%	High Prob > 40%
3-h Snow	> 0.2”	> 0.75”	> 1.5”
24-h Snow	> 1”	> 2”	>6”
3-h Fz Rain		> 0.01”	> 0.05”
Visibility	< 3 mi	< 1 mi	< ½ mi

1/3 of flights canceled at DCA

Future Directions

(Multi vs. Unified Modeling)

Multi-model ensembles are often more skillful and consistent than single ensemble systems

HOWEVER

1) "right" for the wrong reason (complementary biases).

-Can similar skill be attained by post-processing a single ensemble system?

2) technologically complex systems.

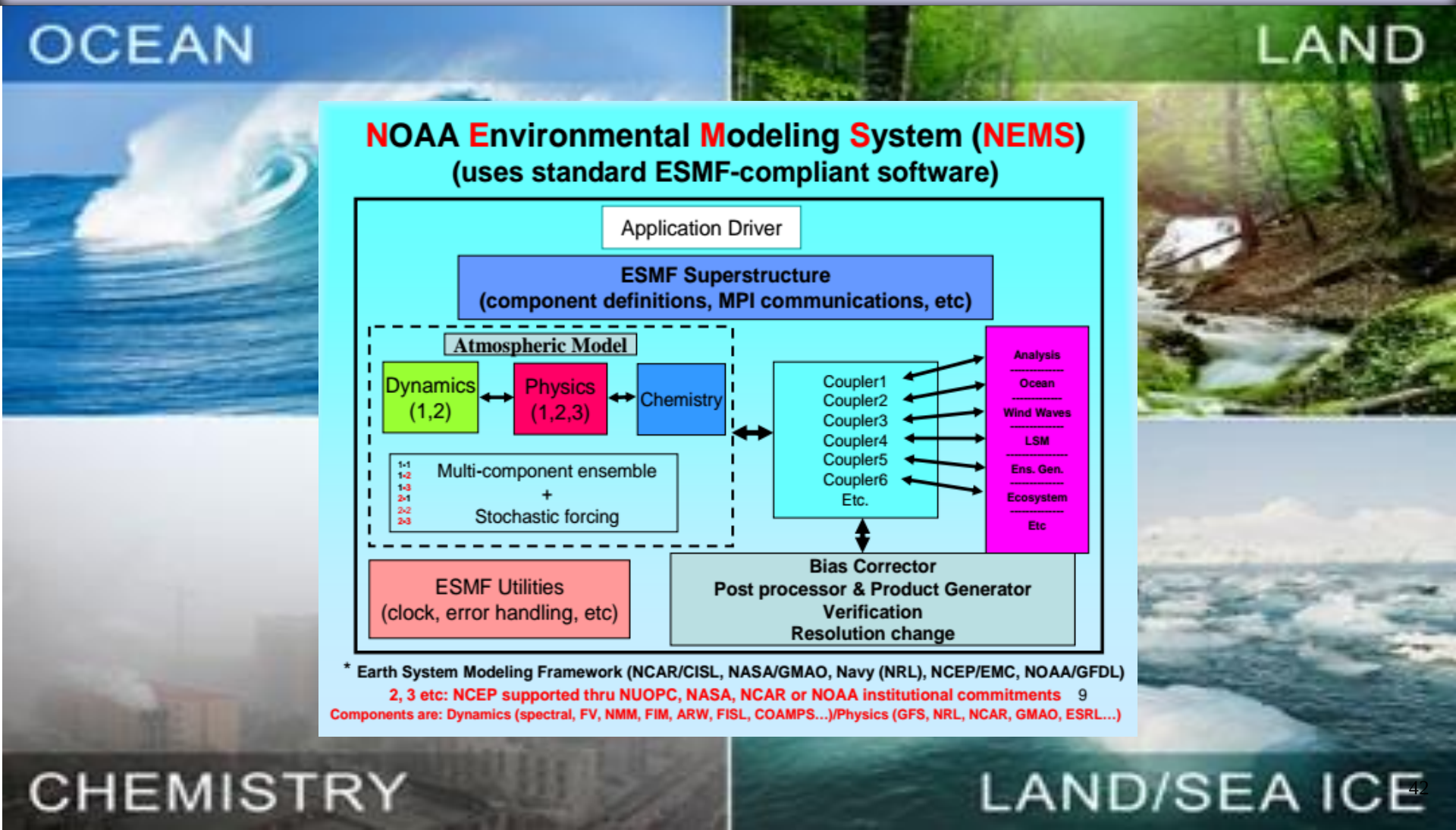
-Requires attention to multiple models

-Does this slow progress on any one model?

-Requires collaboration and data exchange

Future Directions
(Earth System Modeling)

Flexibility to add more complete Earth System components



NOAA Environmental Modeling System (NEMS)
(uses standard ESMF-compliant software)

Application Driver

ESMF Superstructure
(component definitions, MPI communications, etc)

Atmospheric Model

Dynamics (1,2) ↔ Physics (1,2,3) ↔ Chemistry

1-1 1-2 1-3 2-1 2-2 2-3 Multi-component ensemble + Stochastic forcing

Coupler1
Coupler2
Coupler3
Coupler4
Coupler5
Coupler6
Etc.

Analysis
Ocean
Wind Waves
LSM
Ens. Gen.
Ecosystem
Etc

ESMF Utilities
(clock, error handling, etc)

Bias Corrector
Post processor & Product Generator
Verification
Resolution change

* Earth System Modeling Framework (NCAR/CISL, NASA/GMAO, Navy (NRL), NCEP/EMC, NOAA/GFDL)

2, 3 etc: NCEP supported thru NUOPC, NASA, NCAR or NOAA institutional commitments 9

Components are: Dynamics (spectral, FV, NMM, FIM, ARW, FISL, COAMPS…)/Physics (GFS, NRL, NCAR, GMAO, ESRL…)

Future Directions
(Impact Based Decision Support)

- Understand impact of forecasts on society
- Provide decision assistance to core federal, state, and emergency partners

Emergency Response Specialists

- Forecasters who *know thresholds* for critical decisions and *when* critical decisions are made

- Forecasters who *convey probabilistic information* needed for users to make decisions

Future Directions

Modeling	Forecaster	User
A unified system with earth system components (Oceans, Ecosystems, Cryosphere)	Higher-order decision making with greater emphasis on communicating uncertainty and impact	Decisions informed by NOAA's probabilistic environmental intelligence

Summary

Multi-model ensembles:

- **-provide accurate and consistent guidance**
- **-enable forecasters to communicate uncertainty and societal impacts**

Forecasters & users are expanding ensemble use

The Weather Enterprise is moving towards decisions informed by NOAA's probabilistic environmental intelligence

BACK UP

Details of operational ensemble guidance can be found at:

http://www.emc.ncep.noaa.gov/